



**Habitats and areas of particular significance for coastal finfish fisheries management in New Zealand:
A review of concepts and life history knowledge,
and suggestions for future research**

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EXECUTIVE SUMMARY

Morrison, M.A.; Jones, E.G.; Parsons, D.P.; Grant, C.M. (2014). Habitats and areas of particular significance for coastal finfish fisheries management in New Zealand: A review of concepts and life history knowledge, and suggestions for future research.

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Most fished coastal marine teleost finfish have life histories that can be divided up into spawning/reproduction, eggs and larval periods, a juvenile phase, and an adult phase, when reproductive maturity is reached. Elasmobranches vary slightly from this, with some species being live-bearers, while others produce egg capsules that are laid on the seafloor, which eventually hatch as fully formed juveniles. Hurst et al. (2000a) undertook a review of “Areas of importance for spawning, pupping, or egg-laying, and juveniles of New Zealand coastal fish”. This current review follows on from that document, updating our understanding with information generated over the following 12 years, as well as looking at adult migrations and movements in more detail. Thirty eight species which have some component of their life cycle in coastal waters (defined as less than 200 m water depth) are examined, in terms of spawning, oceanographic transport, nursery habitats, adult habitats, adult migrations and movements, and population connectivity and stock structure.

Knowledge across species varies greatly, with species such as snapper, blue cod, rig and school shark being the most heavily researched, while others such as banded stargazer, lemon sole, sea perch, and yellow-eyed mullet having had relatively little or no research effort. For all species, there are large and fundamental knowledge gaps about many aspects of their life histories, and most research that has been conducted has, understandably, been confined to one area/region of a species distribution, rather than over its full range. For some species, work from the 1930s–1960s is still relevant and the best at hand (e.g. lemon sole), with little having been done more recently; while for others, the most relevant work was from the 1970s (e.g. red gurnard, sand flounder and tarakihi). More recent information since the 1990s is largely based around age and growth (not a focus of this review) and general monitoring of stocks using coastal trawl surveys (now confined to the South Island). Recent and/or on-going relevant work is identified for snapper, blue cod, rig and grey mullet.

For most species, there is good evidence of concentrations of spawning fish occurring, often in areas that have been postulated to provide subsequent oceanographic transport of larvae into nursery areas. In some cases, this larval period is very long, with the paper-fish phase of species such as blue moki, tarakihi, and trumpeter extending for up to 9 to 12 months, while hapuku juveniles spend around 2 years in a pelagic phase. Medium to large scale migrations associated with spawning appear to be a nearly universal feature of most fisheries species, as indicated both by indirect inference from fisheries patterns, and from direct tagging of individuals. Tag recapture work, ranging from fewer than a hundred tags to more than 10 000, has been carried out for barracouta, blue moki, blue cod, grey mullet, hapuku, kingfish, rig, sand flounder, school shark, snapper, tarakihi, trevally and yellow-belly flounder. Tag returns showed that many species are capable of making large movements on the scale of several hundred or more kilometres, but also that some individuals are resident and do not move. The apparent movement distribution of many species had most individuals moving relatively short distances, with a long tail of individuals that moved much greater distances. This was true both for species that perhaps might not be expected to move larger distances (e.g. blue cod, flounders), and for others which were much more localised in their movements than might at first be expected (e.g. kingfish). However, most tagging programmes did not allow for formal estimation of movement rates, given unknown variation in fishing pressures across regions (which drive spatial and temporal tag

recovery rates), as well as other factors such as the release of tagged fish *ad hoc* over numerous times and places. Notable exceptions included some snapper and blue cod tagging work

With the exception of west coast North Island snapper, formal definitions of what defines a nursery ground (e.g. Beck et al. 2001, Dalhgren 2006) have not been applied to any species in New Zealand. In the absence of a formal definition, nursery areas were apparent for many species based on higher observed juvenile abundances. Some juvenile (0+) demersal teleost species (e.g. snapper, terakihi, blue cod, leatherjacket) were often associated with three-dimensional seafloor structure, especially biogenic habitats such as seagrass, horse mussels, bryozoans, sponges, and kelp forests. Others were associated with soft sediment environments in settings such as sheltered estuarine waters, e.g., yellow-eyed and grey mullet, sand and yellow-belly flounder. The juveniles of pelagic species such as blue mackerel, the three jack mackerels, and the two warehou species, also occurred in particular areas in much higher abundances, but it was not clear what environmental conditions they were responding to. The nursery grounds of elasmobranchs appear to be especially poorly known, with the exception of recent work on rig, and some localised work on elephant fish.

Connectivity emerged as a key and fundamental theme throughout the life histories of all of the species assessed. This includes migratory and other movement behaviour of adults (including for spawning), egg and larval oceanographic transport, and ontogenetic movement of juveniles from nurseries to adult habitats/areas

Where best to put future research efforts will be affected by many factors, with social and political needs driving decisions as much as biological imperatives. We suggest that regardless of species, key areas of research include better knowledge of spawning aggregations and their vulnerability to disturbance, the transport links between spawning areas and nursery grounds, the ongoing identification and habitat mapping of juvenile nurseries, ontogenetic movement of juveniles from nursery grounds to adult areas, and the nature and role of migratory behaviour, including the existence and consequences of partial migration to populations. Spatial structuring and dynamics at finer scales than that of fish stocks is truly fundamental, and all research needs to have connectivity explicitly included as part of its design and interpretation.

1. INTRODUCTION

Fisheries research and management are (slowly) moving towards a more ecosystem based approach, where fished species interactions and their function within the wider system are explicitly included as part of resource management. The literature around such concepts (Ecosystem Based Management (EBM), Ecosystem Based Fisheries Management (EBFM), and various synonyms) is rapidly expanding, with many viewpoints and different emphases, and is in a state of considerable change. Arguably, no country has yet fully implemented such approaches. Many related concepts (e.g., Essential Fisheries Habitat (EFH), Marine Spatial Planning (MSP)), are more advanced, and starting to be meaningfully applied to real world fisheries and wider marine management. However, regardless of what consensus/synthesis eventually emerges, it is clear that one of the fundamental building blocks for such approaches is a detailed understanding of fisheries species life histories, including where possible bottlenecks that may occur in specific life histories (e.g. nursery, feeding or spawning areas), and how this maps out spatially (known as EFH in the United States). MSP also requires this information, in the form of maps of life histories, and connectivities across time and space between areas, to integrate fisheries management into overall marine resource management. New Zealand is only just starting to explore these themes, and at present the links between concepts and empirical work are modest.

Most fished coastal marine teleost finfish have life histories that can be divided up into spawning/reproduction, egg and larval periods, a juvenile phase, and an adult phase, when reproductive maturity is reached. Elasmobranchs vary slightly from this, with some species being live-bearers, while others produce egg capsules that are laid on the seafloor, which eventually hatch as fully formed juveniles.

Hurst et al. (2000a) undertook a review of “*Areas of importance for spawning, pupping, or egg-laying, and juveniles of New Zealand coastal fish*”. That work included the collation and interpretation of data from research trawl surveys and observer records, and numerous plots of their occurrence, both as presence/absence and abundance. This current review follows on from that document, updating our understanding with information generated over the following 12 years. Additionally, sections are added on movement and migratory behaviour of adults, as these help in ‘closing’ the life history cycle, as well as providing information on how stocks or populations are spatially structured, with connectivity being a key process. Strong evidence of different, multiple behavioural morphs within populations is also emerging, with important influences on growth, mortality and resilience – all important components of managing fisheries. Hurst et al. (2000a) provided numerous plots of *Tangaroa* and *Kaharoa* trawl, and fisheries observer data, by species, divided into juvenile and adult plots, as well as reproductive staging for those species where available. As requested in the RFP for this project, these plots have not been updated, as it was thought that little additional benefit would be gained. The reader is referred back to Hurst et al. (2000a) to access these plots as required. We note that where catch rates from Hurst et al. are given, they are in units of kilograms or tonnes per square kilometre, as these were the metrics used in that report; a ‘number of individuals’ metric is not available.

This updated report expands on the findings of Hurst et al. (2000a), using information that has been published in the last 12 years, including recent work both in New Zealand and overseas. We also include some new thinking and conceptual frameworks that have evolved since that time, for example around nursery habitats and migration dynamics. Hurst et al. (2000a) identified 35 commercially important species that are found regularly in depths of less than 200 m, and for which there were 1) sufficient length-frequency measurements on Research and Observer databases to enable juveniles to be determined, or 2) juveniles were recorded in the FRST programme “*Fish usage of estuarine and*

coastal habitats” which was surveying northern harbours and estuaries at the time. Some of the species (e.g. ling, hake, silver warehou, gemfish) are most abundant and spawn in water deeper than 200 m, but their juvenile distributions were included as they are known to inhabit shallower water. Here we cover 33 of those species, excluding two squid species as they are not finfish. We also include three more species for which information has become available since 2000. These are leatherjacket, trumpeter, and butterfish. A number of fish species have been the subject of tagging work to assess movement; where possible we have included movement maps from those works as they are the clearest way to visualise the work being discussed.

OVERALL OBJECTIVES:

1. To better understand the spatial distribution of important juvenile or reproductive (spawning, pupping or egg-laying) areas for inshore finfish target species in New Zealand.

SPECIFIC OBJECTIVES:

1. To review the literature to determine the most important juvenile or reproductive (spawning, pupping or egg-laying) areas for inshore finfish target species.
2. To use a gap analysis to prioritize areas for future research concerning the important juvenile or reproductive (spawning, pupping or egg-laying) areas for target inshore finfish fisheries

1.2 Scope and limitations of review

Written material, from both the primary and grey literature, was sourced using a combination of key word web search engines (Web of Science, Google Scholar), manual searches of New Zealand science journals, and professional contacts in both science and regulatory agencies. The quality and type of material available varied widely across different sources. Grey literature was included as this holds important information that does not exist in other forms – in fact much of the relevant New Zealand material is not published in primary science journals. As many of New Zealand’s coastal finfish species also occur in Australia (e.g. snapper, school shark, kahawai, blue mackerel, barracouta), or more globally (e.g. grey mullet, John dory, trevally), and/or have closely related species elsewhere, relevant information from overseas studies is included as appropriate. However, it is important to remember that such information is only a proxy for the New Zealand specific content. Feeding is not included in this review’s domain, but is briefly mentioned as appropriate to provide context for the different species. Age and growth are also not included in the scope of this review, although they are mentioned as needed to provide background context.

A brief overview of some primary international literature concepts is given to help provide a framework (albeit one not yet realised for any country) for quantifying and characterising life history and spatial dynamics, in the context of EBM/EBFM. Many concepts are still in development in the science literature, and are only starting to be meaningfully applied to real world fisheries management. New Zealand fisheries managers/researchers are only starting to explore these themes, and at present links between conceptual and empirical work are arguably (very) modest.

This review is also a companion document of sorts to two recent New Zealand focussed reviews: the first on the effects of land-based activities on coastal fisheries and associated biodiversity (Morrison

et al. 2009), and the second on the likely role of biogenic habitats in supporting fisheries productivity (Morrison et al, in revision). There are strong inter-linkages between these different themes, and the research recommendations from these two previous reports are included as Appendices in this current report.

2. A BRIEF REVIEW OF SOME CONCEPTS

Data collected without any clear a-priori hypothesis, or collected as part of a single case study not linked to the testing or integration of any large scale theory or concept, does not optimise the long-term value and return from the data collection, which in marine science is often relatively expensive. While fisheries research is usually ‘operational’ in nature and is driven by the immediate management questions at hand, the move towards more ecosystem based fisheries management has broadened the focus, and it can be argued that fisheries and ecologically driven research are slowly moving towards integration, albeit in an atmosphere of robust debate. Here we briefly cover some relevant themes.

2.1 Spawning

Areas where fish spawn may be disproportionately important to inshore fish populations, as disruption of spawning (whatever the cause) may eventually result in reduced recruitment. Knowledge of where spawning locations are, the dynamics of spawning fish, and the effects of human activity (including direct exploitation occurring at spawning locations), may be important for the maintenance of exploited populations. Spawning activity may range from large spawning aggregations with associated spawning migrations, small localised groups of spawning fish, or single pairs of individuals. All types of spawning events are obviously important to stock/population maintenance. However, when spawning occurs within spatially restricted areas or habitat types, with high proportions of the adult population involved, the possibility of adverse impacts from human activities is greatly increased. Therefore, we focus here on spawning aggregations and/or evidence for spatial restrictions in spawning distributions, as well as potentially detrimental consequences from over-exploitation. Species that predictably congregate in space and time can be extremely vulnerable to overexploitation (De Mitcheson et al. 2008). To date, spawning aggregations have received most attention in tropical reef fisheries (Domeier & Colin 1997, Sadovy & Domeier 2005, De Mitcheson et al. 2008).

A spawning aggregation is defined as “*a group of conspecific fish gathered for the purposes of spawning with fish densities or numbers significantly higher than those found in the area of aggregation during the non-reproductive periods*” (Domeier & Colin 1997). There are two types of spawning aggregations: resident (where fish travel short distances); and transient (where fish travel larger distances with aggregations lasting for a short portion of the year). Spawning aggregations often occur over specific topographical features and at specific times. These features and times may provide optimal gamete dispersal or larval retention near good settlement habitats, reduce egg predation, maximise larval food encounter rates, or synchronise reproduction efforts and maximise fertilisation rates. The same spawning aggregation sites can be repeatedly used year after year, with knowledge of these specific sites likely to be learnt from experienced individuals through the social transmission of knowledge (Warner 1988, 1990). In a global database compiled by the Society for the Conservation of Reef Fish Aggregations, 60% of known aggregations of large tropical reef fish were in decline while a further 20% no longer formed (Sadovy & Domeier 2005).

One of the best known examples of exploitation of an aggregating tropical reef fish is that of Nassau grouper (*Epinephelus striatus*). Nassau grouper were once the most commonly landed species in the

Caribbean and tropical western Atlantic (Sadovy & Domeier 2005), but are now classified as endangered by the World Conservation Union. Nassau grouper aggregate to spawn at relatively few locations but in high numbers (up to 30 000 to 100 000 fish). The majority of catches that supported the fishery for Nassau grouper were taken by traditional fisheries at these aggregation sites. Of the aggregation sites that have been resurveyed, all were in decline with very few fish present at some sites (Sadovy & Domeier 2005).

In New Zealand, over-exploitation should not (in theory) occur in aggregation fisheries because of overall catch restrictions under the Quota Management System (QMS). However, this assumes that all fish 'are equal' whenever and wherever they are removed by fishing. It does not allow for the possibility that removal of fish from spawning aggregations may detrimentally disrupt the spawning success of the overall aggregation (including fish not removed); or that the over-exploitation of specific spawning aggregations may result in lower recruitment in the surrounding areas that are subsequently supplied with larvae, given the existence of spatial population dynamics at more local scales than that of fish stocks. Other possible impacts might include the damage of seabed structure necessary for successful spawning, the bias of sex ratios, the removal of older age classes which contribute the most to recruitment, and even the abandonment of aggregations. There has to our knowledge been no work on such possibilities in New Zealand species; although there is strong disagreement as to whether such processes would be important in the context of the QMS. These potential impacts ultimately affect recruitment processes via egg and larvae production, which are often presumed to be largely determined by environmental processes during the oceanographic phase (pre-settlement), and not stock spawning size. It is acknowledged that disruption of spawning aggregations at low stock sizes may result in reduced recruitment (Hurst et al. 2000a). We argue that given the emerging importance of biocomplexity in fish populations, including different behavioural morphs, skipped spawning, maternity effects, and source-sink dynamics; as well as increasing human disruption of all aspects of coastal ecosystems; that spawning aggregations need to be better understood, and more explicitly managed.

A clear New Zealand example of how specific fish spawning behaviours can make them more vulnerable to particularly adverse fishing impacts comes from Tasman Bay, at the top of the South Island. During the late 1970s and early 1980s spotter planes were used to guide fishing vessels to dense surface schools of snapper during the snapper spawning season, until the fishery eventually collapsed. This surface schooling behaviour has not been seen elsewhere in New Zealand, but in Western Australia surface schools of highly aggregated and ripe snapper are observed in a variety of nearshore embayments (Wakefield 2010). These aggregations are thought to represent the majority of spawning activity along the Western Australian coast (Wakefield 2010).

2.2 Nursery habitats

Many fish species use specific areas as nursery grounds for juveniles, with adults often being found in other areas, with ontogenetic migrations linking the two. The definition of what is a nursery habitat/area has received a lot of attention, following the recognition that the simple presence of juvenile fish does not automatically equate to a particular habitat or area providing an important nursery function. A clear definition is required to ensure that researchers, managers and others understand each other, and to minimise confusion and miscommunication that results in less effective and efficient research and management outcomes.

Beck et al. (2001) led this way of thinking, by specifying what conditions need to be met in order for a habitat/area to be seen as providing a nursery function. Reviewing the literature, they concluded that

ecological processes operating in nursery habitats, relative to those in other habitats, must support greater contributions to adult recruitment from a combination of the following four factors: (1) higher densities per unit area, (2) greater growth rates, (3) higher survival of juveniles, and (4) movement of juveniles to adult habitats. They argued that to fit the ‘nursery-hypothesis’, species must be considered to have ‘nursery habitats’ that have at least some spatial disjunction between juvenile and adult habitats and that movement to non-juvenile habitats must be associated with reproduction. They also noted that many other life history strategies existed – and that the nursery hypothesis did not imply that, for example, seagrass meadows did not have important effects on species which spent their entire lives there (i.e., had no juvenile and adult phase spatial segregation). Examples that they gave for species which did not have nurseries, per se, included bay scallops (*Argopecten irradians*), killifish (*Fundulus* spp.), bay anchovy (*Anchoa mitchilli*), and amphipods (the first three species are North American). Species they did recognise as having nurseries included clawed lobster (*Homarus americanus*), eels (*Anguilla*)*, red drum (*Sciaenops ocellatus*), gag grouper (*Mycteroperca microlepis*), blue groper (*Achoerodus viridis*), pink snapper (*Pagrus auratus*)*, luderick/parore (*Girella tricuspidata*)*, tarwhine (*Rhabdosargus sarba*), blue crabs (*Callinectes sapidus*), brown shrimp (*Farfantepenaeus aztecus*), flounder (*Paralichthys* spp.), pinfish (*Lagodon rhomboides*), grey mullet (*Mugil cephalus*)*, and gray snapper (*Lutjanus griseus*) (*, New Zealand species).

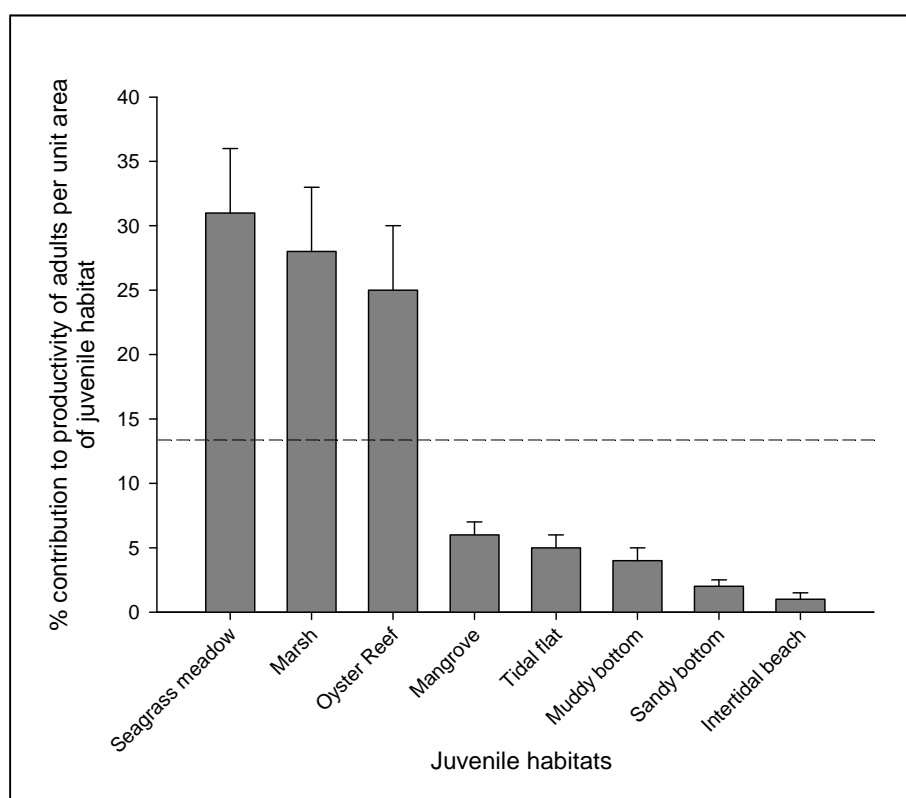


Figure 1: A hypothetical comparison of the nursery value of several different habitats. The dashed line represents the average percentage productivity of adults per unit area from all the juvenile habitats. In this example, seagrass meadows, marshes, and oyster reefs are nursery habitats (Source: figure 4 of Beck et al. 2001, reproduced with permission).

Beck et al. (2001) listed a range of conditions and tests required to be met for a habitat to be considered a nursery habitat (NH). Even very spatially discrete habitats could qualify as important nursery habitats – as long as they produced relatively more adult recruits per unit of area than other juvenile habitats used by a species (Figure 1). Conversely, some habitats might contribute individuals

to adult populations, but make a less than average contribution relative to other habitats – these would not qualify as nurseries using Beck et al.’s definition. Measuring the movement of individuals from juvenile to adult habitats was considered an essential component of nursery habitat quantification, with the best integrated measure of a given habitat’s contribution being the total biomass (i.e. production) of individuals recruiting to adult populations from that habitat. Although a habitat might support high densities of juveniles, if those individuals did not reach adult populations (e.g. the habitat was acting as a ‘sink’), then that habitat was not functioning as a productive habitat. Examples of processes which might bring about such a situation included high larval settlement into sites where growth was poor, or where movement to adult habitats was risky or difficult (e.g. no adult habitats nearby, or particularly intense predation, Lipcius et al. 1997, McBride & Able 1998).

Beck et al. (2001) also stressed the importance of taking into account variation in habitat values within a given habitat, and noted that not all occurrences of a given habitat should be considered equal. Examples included geographic variations in the importance of widely distributed habitats, in habitat quality (e.g. seagrass blade density), in larval supply and settlement, and in the local landscape configuration in which habitats were embedded (Table 1). As an example, they noted that conservation and management agencies now commonly consider all seagrass and wetlands as nurseries, and that while these broad declarations were useful for generating public interest, they hindered the actual work that needed to be accomplished by these groups because the statement lacked focus. By gaining a clearer understanding of what makes some sites more important than others as nurseries, more efficient use of limited money, time and effort could be achieved by targeting the most critical elements of the system. Beck et al. (2001) concluded that while idealistically the level of evidence required for showing a habitat to be a nursery was very high and very difficult to achieve, it could be seen as providing a view of what a definitive test would encompass, “*so that researchers could arrive at the best approximation of it*”. Examples of themes researchers might best focus on included: factors of density, growth, survival, and movement in putative nursery habitats; the quantification of multiple habitats for a given species; and a better quantification of the movements of individuals between juvenile and adult habitats. They also commented that correlative and case study analyses could also yield many useful insights – such as correlations between inshore habitat loss and offshore fisheries production (e.g., Butler & Jernakoff 1999).

Table 1: Factors that create site-specific variation in nursery value (Source: table 1 of Beck et al. 2001, reproduced with permission).

Biotic	Abiotic	Landscape
Larval supply	Water depth	Spatial pattern (e.g. size, shape, fragmentation, connectivity)
Structural complexity	Physicochemical (dissolved O ₂ , salinity)	
Predation		
Competition	Disturbance regime	Relative location (e.g. to larval supply, other juvenile habitats, adult habitats)
Food availability	Tidal regime	

Dalhgren et al. (2006) further developed the nursery concept to allow for situations in which average densities per unit of habitat might be relatively low, but where the overall extent of those habitats was such that they still provided a significant proportion of recruits to the adult population. Such habitats

would not be identified as nursery grounds (NH) under the definitions of Beck et al. (2001). Dahlgren et al. proposed the term Effective Juvenile Habitat (EJH) to describe “*habitat for a particular species that contributes a greater proportion of individuals to the adult population than the mean level contributed by all habitats used by juveniles, regardless of area coverage*”. While similar to the definition used by Beck et al. (2001), the key difference was that for EJH, “*the contribution of individuals from juvenile habitats to the adult population is based on comparisons of the overall contribution that the habitat makes, rather than the per-unit-area comparisons required for nursery habitats*”. The EJH definition does not require an estimate of the areal extent of each contributing habitat. However, the evaluation of the importance of juvenile habitats using the two classification schemes can result in considerable differences (Table 2).

Table 2: Hypothetical example showing the difference between habitats classified as Effective Juvenile Habitat (EJH) and Nursery Habitat (NH; following the definition of Beck et al. 2001). EJH is determined from the overall contribution of each habitat. NH is calculated by dividing the overall contribution of each habitat by the area that the habitat comprises (on a measured area or percentage basis). EJH determines whether the contribution of a habitat is greater than the average contribution of all habitats (14.3%); NH determines whether the contribution/area for a habitat is greater than the average contribution/area for all habitats (Source: table 1 of Dahlgren et al. 2006, reproduced with permission).

Habitat	Contribution (%)	EJH	Area (% or km ²)	Contribution area ⁻¹	NH
Sand	3.0	No	40.0	< 0.1	No
Seagrass	30.0	Yes	30.0	1.0	No
Hard bottom	2.0	No	20.0	0.1	No
Mangrove	20.0	Yes	5.0	4.0	No
Patch reef	30.0	Yes	3.0	10.0	Yes
Algae	10.0	No	1.0	10.0	Yes
Artificial	5.0	No	1.0	5.0	Yes
Total	100.0		100.0	30.2	
Mean	14.3		14.3	4.3	

Dahlgren et al. (2006) argued that, given the use of natural or artificial markers, which are unique to different juvenile habitats and are preserved as animals move to adult habitats, researchers could estimate where animals were derived from, and in what proportions, providing a direct estimate of EJH. This served the purpose of broadly identifying important habitat types, and was particularly useful in focussing marine resource management, (e.g., around habitat protection, and protection of juveniles from threats such as capture as by-catch, or water quality issues), at broader spatial scales. Conversely, the NH approach, which required the mapping/areal estimation of all contributing habitats, was most suited to identifying specific high quality habitats for conservation, restoration, and management – specifically in the prioritisation required for spatially explicit management (e.g., Marine Protected Areas, MPAs, or restoration), where resources were limited. However, the need for mapping made the NH approach more intensive and expensive than the EJH approach. Which

approach to use was context dependent, relative to the management questions being addressed, and the associated level of resourcing available.

Neither the NH or EJH concepts have (to date) been applied to New Zealand fish (or invertebrates) and associated fisheries, with the exception of mangrove habitats and small fish (Morrissey et al. 2010), and of snapper along the west coast of the North Island (SNA 8) (Morrison et al. 2009), focussing on the nursery role of the estuaries that occur along that coast.

In the species section of this report, we do not attempt to formally apply the NH or EJH concepts, as that is well beyond the scope of this report. Additionally, knowledge of almost all species is currently insufficient to do so. Hence the use of phrases such as juvenile habitats and nurseries are used in a general descriptive sense, and have not been subjected to formal analyses of what proportion of actual recruitment they provide to adult populations and stocks.

2.3 Migrations and movements

On even a cursory look at almost any of New Zealand's coastal finfish fishery species, it becomes immediately apparent that migratory behaviour is a key component of their life history, especially in the adult phase. Dingle & Drake (2007), in a review of migration including many animal groups, not just fish, stated that: *“migrating animals are found in all major branches of the animal kingdom, their journeys take place in a variety of media, and they move by flying, swimming, walking, or drifting. Despite this variety, however, it is apparent that we are dealing with a single biological phenomenon that transcends taxon, form, and environment but that relates directly to one of the most universal and defining traits of animals: their mobility.”*

Dingle & Drake (2007) suggested a classification of migratory patterns, based on whether the focus was on the organism, the spatial or temporal attributes, or the medium in which the migration took place (Table 3). Within this they further divided migration into a number of types (Table 4).

Table 3: Variation in patterns of migration (from Dingle & Drake 2007, reproduced with permission).

Category	Pattern
Organism	Obligate, facultative, partial, differential
Space	To-and-fro, round-trip (loop), one-way, attitudinal, nomadic
Time	Seasonal, irruptive
Medium	Diadromic, drift (including devices)

Table 4: Types of migration (from Dingle & Drake 2007, reproduced with permission).

Obligate or facultative	Depending on whether they always migrate or do so only in a proximate response to current deterioration of local conditions. In practice, however, the distinction is often blurred.
Partial	A fraction of the population remains either in its breeding or its nonbreeding area while the remainder moves away.

Differential	There are differences in the migration patterns of older and younger individuals or of the two sexes.
To-and-fro	Is what we call here “ <i>two worlds</i> ”; round-trip migration is a variant of this in which animals return to the general breeding area from which they originated but may stage their movements through a succession of nonbreeding areas, and perhaps follow different paths on the outward and return journeys (<i>loop migration</i>).
One-way	Found mainly in insects and marine larvae, carry animals from a location where they were produced to another where they breed and produce the next generation (or generations) before dying; a succession of such one-way movements through a series of breeding areas may form a multiple-generation round trip.
Vertical	Occur between different water depths (and are actually a form of “ <i>commuting</i> ” rather than migration); <i>altitudinal</i> migrations occur between different terrestrial elevations.
Nomadism	Migration does not follow a regular pattern or route but links temporary breeding sites that are located where conditions are ephemerally favourable.
Annual	Migrations are round trips synchronized with the annual cycle; <i>seasonal</i> migrations are particular stages of these annual journeys.
Irruptions	<i>Irruptions</i> are occasional, irregular movements of a significant proportion of a population beyond its usual breeding or nonbreeding area.
Diadromic	<i>Diadromic</i> migrations take fish (and some crustaceans) between fresh and salt water. Another distinction is between movements achieved primarily by transport on a wind or current (sometimes referred to as <i>drift</i>) and those resulting essentially from locomotion <i>through</i> a medium. Special evolved devices, such as the ballooning threads of spiders and some larval insects, are sometimes employed to promote drift (Dingle 1996).

Recognising that migration is a single phenomenon, Dingle & Drake tried to provide a conceptual model which they termed a “*migration system*”. This incorporated both components and processes, including the environment, within which the migrant population exists, as well as the migrant’s responses and adaptations to that environment (Figure 2 below). The four system elements were: 1) a *migration arena* comprising the environment (including biotic elements) to which the migrants are adapted [i.e. the habitat landscape, both demersal and pelagic]; 2) a *migration syndrome*, the suite of traits enabling migratory activity, with this suite comprising both locomotory capabilities and a set of responses (or nonresponses) to environmental cues that schedule and steer the locomotory activity; 3) the *genetic complex* that underlies the syndrome; and 4) a *population trajectory* (or its long-term average, the *population pathway*) comprising the route followed by the migrants, the timing of travel along it, the points along it where migration temporarily ceases, and the times when these points are occupied for breeding and other key life stages. This model incorporated both the ultimate (selective) and proximate factors acting on migration (the arena), the response to natural selection in the phenotype and genotype of migrants (the syndrome and its genetic complex), and the population consequences in terms of both selection and current conditions.

In the context of current New Zealand coastal fisheries management, what relatively limited work has been done on migrations has focussed largely on elements 1) and 4); i.e., broadly describing migrations as a means of investigating stock extents and where stock boundaries may occur. How migration actually works, and what its consequences are to population dynamics (e.g. productivity, resilience, stability) have not been examined. Similarly, genetics work has been entirely focussed on defining stock units.

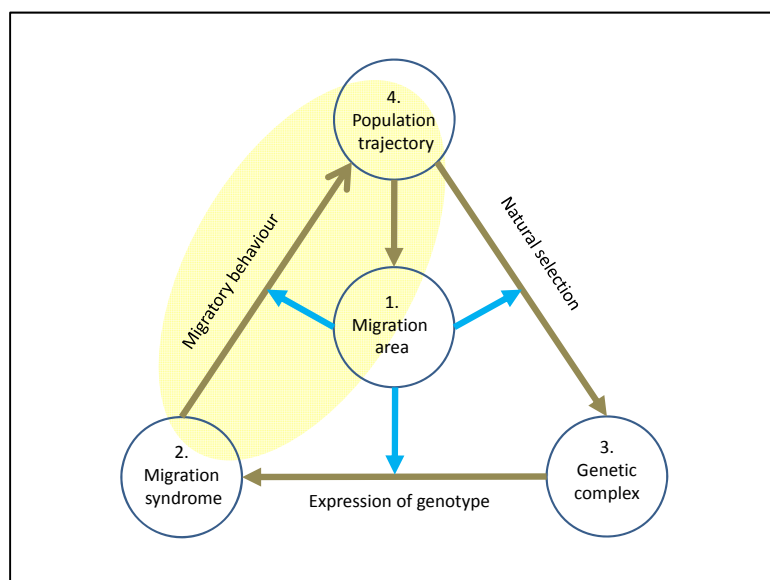


Figure 2: Holistic conceptual model of migration. The four blue circles represent the primary components; the long fawn arrows the principal processes connecting them; and the blue arrows the primary modes of environmental influence. The short fawn arrow represents the impact of the population on its habitat, including exhaustion of resources, and introduction of pathogens (a New Zealand example would be the trophic cascades on some Hauraki Gulf shallow rocky reef systems, through snapper and rock lobster predation on urchins, and subsequent re-establishment of kelp forests). Natural selection occurs through differential mortality and through the process of spatial partitioning, in which different phenotypes steer individuals (and the genes they carry), to different destinations (see text below for the potential role of partial migration in fisheries). We have added the background yellow shaded oval; this is the area on which New Zealand coastal fisheries migration research (largely tagging programmes) have been focussed. Phenotype/genotype interactions, migratory drivers and consequences, and the role of genetics (beyond seeking to identify stock units), have been largely ignored in coastal fisheries management. (Source: Dingle & Drake 2007, reproduced with permission).

Given the above discussion on migration and its structuring, how then does this specifically relate to fisheries? As an example, partial migration is receiving increasing attention in the marine fisheries literature, with a key series of papers by Kerr and co-authors. As defined in Table 4, partial migration is the phenomenon in which coexisting groups within the same population exhibit both migratory and resident behaviour (Kerr et al. 2009). Initially developed in the bird literature, more recently it has been applied to salmonoids in North America, and their ecophenotypes. Kerr et al. (2009) suggested that partial migration has been overlooked in traditional fisheries stock assessment, due to an emphasis on closed population assumptions, and the confusion created by the use of multiple different terms to describe the same phenomena (Secor 1999, Cadrin & Secor 2009, Secor & Kerr 2009). They suggested that partial migration is a widely applicable and useful concept for understanding fish life cycles, providing “a mechanistic understanding of the evolution, control and adaptability of migratory behaviour (Berthold 2001)”. They proposed that mechanisms for the maintenance of partial migration (within bird and salmon populations) included: (1) a conditional strategy, whereby an

individual's genetic makeup allowed for the adoption of resident or migratory behaviour based on an interaction between individual physiological condition and the environment (Gross 1996, Gross & Repka 1998, Lundberg 1988); (2) frequency-dependent selection of the migratory tactic (i.e., an evolutionary stable strategy; Lundberg 1988, Gross 1996), and (3) genetic polymorphism, whereby the two morphs represent reproductively isolated sub-populations (Lundberg 1988, Verspoor & Cole 1989).

As a specific case study, Kerr et al. (2009) looked at white perch (*Morone americana*), a dominant and cosmopolitan species in Chesapeake Bay, North America. Classified as a semi-anadromous species (moving between fresh and brackish tidal waters), it was traditionally thought that all white perch moved into brackish waters during their late-juvenile to adult stage, with adults returning to freshwater habitats in the spring to spawn, with eggs and larvae then developing in this environment. However, the recent use of otolith chemistry (Sr/Ca ratio trajectories) has shown that divergent habitat usage exists, with some of the population remaining resident in the natal freshwater region, and a second portion of the population dispersing into brackish water (salinity under 3‰) environments (Kraus & Secor 2004). This divergence in habitat use occurs after the transition from larval to juvenile stage. In addition, the relative proportion of the population in each category varied across years, in response to environmental conditions, i.e. stream flow. Within a particular year-class, the percentage of white perch that remained resident during their first year of life ranged between 4% in high flow years, 15% in low flow years, and 100% in drought years (Kraus & Secor 2004). Resident fish were observed to grow significantly more slowly than those that migrated, as measured over a lifetime (adult fish assigned to a behaviour group, based on their Sr/Ca ratios) (Kraus & Secor 2004, Kerr et al. 2009). Kerr et al. (2009) also suggested that the resident fish were expected to have lower reproductive rates and fitness compared to the migratory portion of the population. Balancing this, they suggested that evidence from other studies indicated that the benefits of migration into higher salinity waters may be offset by higher predation risk in these deeper estuarine environments (Miltner et al. 1995, Paterson & Whitfield 2000). Additionally, the faster juvenile growth rates exhibited were suggested to be potentially offset by the physiological costs of accelerated growth such as reduced predator evasion (Metcalf 1998, Billerbeck et al. 2001, Mangel & Stamps 2001).

Kerr et al. (2009) argued that such partial migration was likely to be widespread in fish taxa. Two notable examples given were the existence of resident and migratory components in Atlantic bluefin tuna (*Thunnus thynnus*) population, whereby a portion of the population completes its life cycle within the Mediterranean Sea and others migrate into the Western Atlantic (Rooker et al. 2007); and Gulf of Maine cod (*Gadus morhua*) which exhibited resident and migratory morphs (Wroblewski et al. 1994) that may be structured through partial migration.

Kerr et al. followed on their work with a subsequent paper which modelled the likely outcomes to populations of such partial migration behaviour. Kerr et al. (2010) used age-structured models to assess a population composed of resident and migratory contingents (behavioural groups within populations that exhibit divergent life histories), linked through a common stock recruitment relationship. It was assumed that these resident/migratory behaviours were not genetically inherited, and that a fish could actively select a strategy early in its life history. They evaluated the role that contingents played in mitigating population responses to unfavourable environmental conditions. Population dynamics were most sensitive to the proportion of individuals in each contingent, and to a lesser degree to the level of correlation in recruitment between contingents, in their responses to the environment (Figure 3). Increased representation of the dispersive contingent within populations resulted in increased productivity and resilience, but decreased stability. A high negative correlation in resident and dispersive contingent recruitment dynamics resulted in increased productivity and

stability, with little effect on resilience. With high positive correlation between contingent recruitments, the model showed similar responses in population productivity and resilience, but decreased stability. Collectively, contingents provided a risk-spreading strategy, providing for maintenance of the population, while also allowing for populations to take advantage of periods when environmental conditions were favourable for population expansion. Kerr et al. (2010) concluded that because contingent structure involves differing patterns of nursery habitat use, spatial management which conserves sets of habitats rather than the single most productive nursery habitat would be expected to contribute to long-term population stability. This differs somewhat from the suggestions of Beck et al. (2001) and Dahlgren (2006), through the inclusion of different behavioural morphs, with an associated increase in the role of spatial biocomplexity.

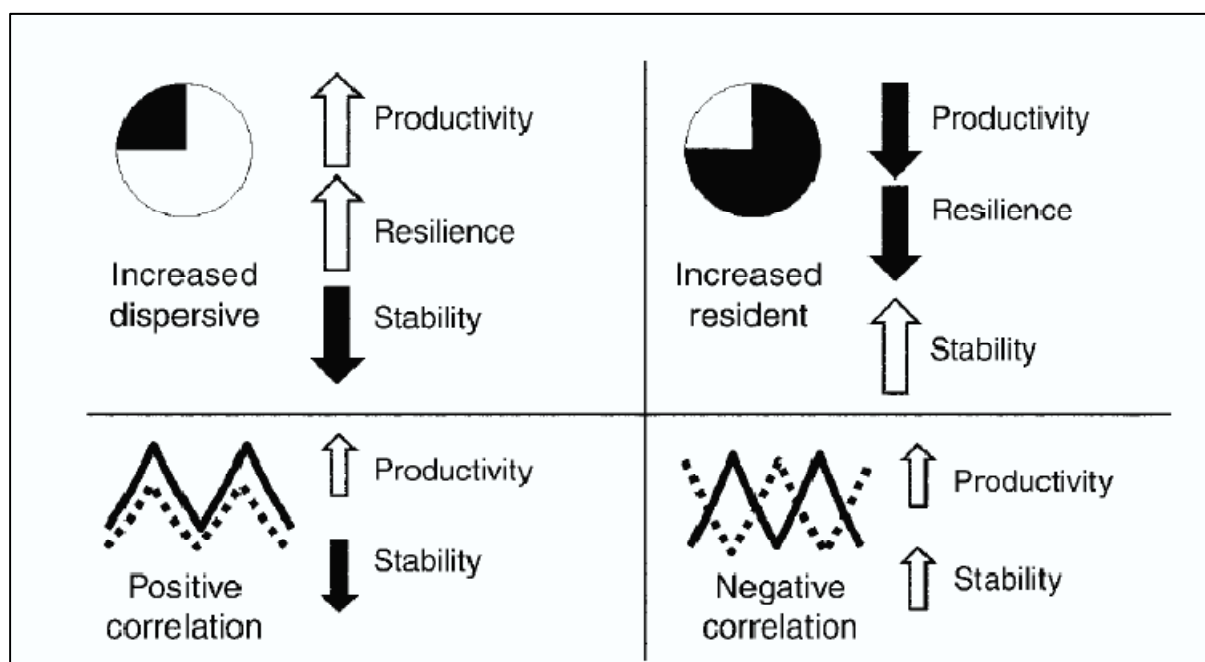


Figure 3: Summary graphic of simulation modelling results from Kerr et al. (2010). The effects of increasing dispersive or resident fish contingents are shown, as well as the effects of positive or negative correlations between the contingents over time (generations). Productivity is defined as spawning stock biomass, resilience as time to recover from disturbance, and stability as the coefficient of variation of spawning-stock biomass (Source: figure 4 of Kerr et al. 2010, reproduced with permission).

As will be seen in the following sections, there is clear and increasing evidence that many New Zealand coastal fish species also display both resident and migratory behaviour. Such dynamics are not currently allowed for in associated fisheries management regimes.


2.4 Spatial biocomplexity, populations, and stocks

Fisheries management is invariably based on the concept of fisheries stocks. Definitions of the term “fisheries stock” vary, and have altered over time (Begg & Waldman 1999). In general, stocks can be considered as arbitrary groups of fish, large enough to be essentially self-reproducing, with members of each group having similar life history characteristics. In a fisheries sense, stocks are usually smaller than natural biological populations, but reflect many characteristics of these populations (Paul 2005a). However, there is increasing evidence emerging that spatial and temporal complexity in populations (‘biocomplexity’) is much higher and more important to population dynamics than has previously been thought. Reviewing this conceptual area is no small task, and beyond the scope of this present report.

Here, we use the term ‘stock’ and ‘population’(s) largely interchangeably, as distinctions between the two are poorly defined in the New Zealand context. Intuitively, stocks may consist of a number of interacting populations which have sufficient exchange of individuals to connect them over ‘ecological time-scales’, but which also have their own internal dynamics, that may include natal homing, sources and sinks, and movement/migration corridors. These concepts all fall under the domain of ‘landscape ecology’, which is well advanced for terrestrial ecosystems, and has recently also starting gaining traction in marine ecosystems. The literature around these and related concepts is large and expanding, and well beyond the ability of this report to review and summarise, but they are likely to become increasingly important as fisheries and ecological science streams merge in the context of ecosystem based management.

3. INDIVIDUAL SPECIES LIFE HISTORY INFORMATION

3.1 Banded giant stargazer (*Kathetostoma binigrasella*)

<p>Fisheries catch: Commercial: Unknown, but included in catch records for <i>K. giganteum</i>, especially in less than 400m depth¹ Recreational: Unknown</p> <p>Sexual maturity: Unknown</p> <p>Maximum age: Unknown years / 79 cm²</p> <p>Pelagic phase duration: Unknown</p>	 <p>© NIWA P. Shearer</p>
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¹Gomon & Roberts (2011), ²McMillan et al. (2011)

Previously known as *Kathetostoma sp.*, the banded stargazer has been recently re-described (Gomon & Roberts 2011). This species is widespread and relatively common in coastal and offshore waters, from the Wanganella Bank (southern Norfolk Ridge) to the Snares shelf, including the Chatham Rise. This species is generally found in water depths of 10–500 m, but is commonly found between 100 and 300 m (Gomon & Roberts 2011). Despite its recognition for more than 25 years, this species has been confused with giant stargazers - *Kathetostoma giganteum* in literature and fisheries catch data. Records of New Zealand giant stargazers probably include both species; especially where capture depths are less than 400 m. Based on confirmed records, population sizes of this species are smaller than those of its congener.

Spawning

Fish have been reported to spawn on the Southland shelf, mainly along the shelf edge, with one record of a spent fish from the Chatham Islands (Hurst et al. 2000a).

Egg and larval transport

Unknown

Nursery habitats

Hurst et al. (2000a) reported that immature fish have been caught in most trawlable areas over the Southland shelf (75–350 m), except for the north-east areas south of Otago Peninsula. Juveniles were

reported only from *Tangaroa* middle depth trawl surveys, mainly off Southland, with low catches, with a peak value of 56 kg.km⁻² west of Solander Island.

Adult habitats

The distribution of the newly described banded giant stargazer is wider than previously suggested – traditionally it was considered most common off Southland in waters 30–300 m deep, with limited records from the Chatham Islands, off the Wairarapa Coast and at the Auckland Islands. It is now known to also occur on the Snares shelf, on the eastern Chatham Rise, the west coast of the North Island and in the northern Tasman Sea (Smith et al. 2006).

Movement dynamics

Unknown

Ontogeny

Unknown


Adult migrations and movements

Unknown

Population connectivity

Unknown

3.2 Barracouta (*Thyrisites atun*)

<p>Fisheries catch: Commercial: 32 672 t ¹ Recreational: 250–500 t ^{2*}</p> <p>Sexual maturity: 50–60 cm / 2–3 years ³</p> <p>Maximum age: 10 years ⁴</p> <p>Pelagic phase duration: Eggs: hatch after 50 hours ³ Larvae: Unknown, settle at 15 mm ⁴</p>	
<p>¹MPI web site - for the 12 month period to 30/09/2011; ²MPI Assessment Plenary Document, Part 1, (2012);* Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ³Hurst (1988); ⁴Hurst & Bagley (1987); ³Haigh (1972) ⁴Neira et al. (1998).</p>	

Barracouta are a benthopelagic predator, often forming schools near the bottom, in midwater and sometimes at the surface at night, and feed on crustaceans (e.g. euphausiids and *Munida* spp.), cephalopods and small pelagic fish (O'Driscoll 1998, O'Driscoll & McClatchie 1998). As well as New Zealand, they are found across the southern hemisphere in temperate shelf waters and around islands, including southern Africa, Australia and southern South America, often linked to a temperature range of 13°–18°C (FishBase 2012), between latitudes 25° to 58° S (Horn 2002).

Spawning

Spawning aggregations are widespread around New Zealand, occurring in late winter/spring (July/August–September/October) on the west and east coasts of both islands (Hurst, 1988). This species is thought to be an indeterminate serial spawner (Griffiths 2002); Beentjes & Stevenson (2001) noted the presence of secondary 1+ age modes in the length frequency for this species in the summer inshore trawl surveys of the east coast South Island. These spawning aggregations are

targeted by commercial fisheries, with spawning fish making up a significant proportion of commercial catches during August to October (Langley & Bentley 2002). There is a well-defined spawning season off the west coast of the South Island between August and October, with a secondary peak in February. Hurst & Bagley (1998) surveyed the Cape Foulwind to Cook Canyon area in early September, and found that “...catch rates of barracouta and some of the other main species were significantly greater in the southern half of the survey area, between Hokitika Trench and Cook Canyon. Several species were spawning or about to spawn in the period of the survey, namely barracouta...” O’Driscoll (1998) also commented that he had “observed extensive surface schools of barracouta off Cape Palliser, in the North Island of New Zealand, during August. Fish captured from these schools had very little in their stomachs, but their gonads were ripe, suggesting that these may have been reproductive aggregations”. Anecdotal information also suggests spawning occurs off the west coast of the North Island (R. Hurst pers. comm., in Langley & Bentley 2002) and a small but consistent mode of juveniles (15–25 cm) were also recorded in a number of trawl surveys in this area (Morrison & Parkinson 2000). On the east coast of the South Island, spawning fish occur to a lesser extent off the Canterbury Bight and north of Kaikoura, with a relatively high proportion of spent fish present from December–February. Along the east coast of the North Island, extending up to the Bay of Plenty, spawning fish occur from August–October. Spawning takes place slightly later in coastal Southland (October–December), in shallow areas east of Stewart Island, along the Solander Corridor, along the edge of the Snares shelf, on Mernoo Bank; while around the Chatham Islands the spawning period extends from November–December (Robertson & Mito 1979, Hurst & Bagley 1987).

Egg and larval transport

Work off South Africa shows that barracouta eggs hatch about 50 hours after fertilization, consume phytoplankton from first feeding (3.5 mm, 3–4 days after hatching), until 8 mm standard length, and then prey mainly on the larvae of other fishes (Haigh 1972). Eggs are found in the coastal waters of central and southern New Zealand (Robertson 1975) and larvae are probably transported by the prevailing currents to inshore nursery grounds (*sensu* Griffiths 2002), where they settle at a body length of around 15.7 mm (Neira et al. 1998).

Nursery habitats

Juvenile 0+ barracouta are widespread in New Zealand coastal waters less than 200 m in depth, while 2+ fish have a similar distribution, which extends slightly further offshore (Hurst et al. 2000a). However, the inshore west coast South Island trawl surveys show pre-recruits (less than 4+) to be largely restricted to Tasman and Golden Bays, and less common on the west coast proper (Stevenson & Hanchet 2000b); a particularly strong 0+ mode (20–25 cm) was noted in the 2009 survey (Stevenson & Hanchet 2010). The inshore waters around Banks Peninsula, including the Canterbury Bight and Pegasus Bay, also support higher numbers of juvenile barracouta, with a 0+ mode (10–20 cm) being recorded in both the discontinued summer (December–January) and the on-going winter (May–June) east coast South Island trawl surveys. Juvenile catch rates are highest (up to 7.1 t km⁻²) in the Canterbury Bight (Hurst et al. 2000a). Juveniles have also been recorded in trawl surveys in coastal waters around Stewart Island, off the Otago Peninsula, and around the Chatham Islands (up to 8.99 t km⁻²) (Hurst et al. 2000a). Around the North Island, a 0+ mode (15–20 cm) was recorded along the south-east coast of the North Island (particularly Hawke Bay) between 50–200 m water depths, in February–March, with peak catch rates of 1.6 t km⁻² (Stevenson & Hanchet 2000a). Catch rates of 1.2 t km⁻² have been recorded in the Hauraki Gulf, but there are fewer records from the west coast North Island (Hurst et al. 2000a).

Adult habitats

Barracouta occur in coastal waters around mainland New Zealand, across shallower parts of the Chatham Rise and occasionally in the Sub-Antarctic, down to about 400–450 m (Anderson et al. 1998, Bagley et al. 2000, Hurst et al. 2000a). In the inshore South Island trawl surveys, barracouta are consistently amongst the most abundant species, with highest catches in less than 200 m, particularly in the central Canterbury Bight east of Timaru (Hurst et al. 2000a). Catches are more variable in trawl surveys of the west coast of the North Island, with low or no catch north of the Manukau and/or Kaipara harbours in some years (Morrison & Parkinson 2000)

Adult migrations and movements

Patterns in commercial fishing and tagging experiments have shown that barracouta undertake extensive alongshore migrations between feeding and spawning areas. Hurst & Bagley (1989, Figure 4 below) tagged 4907 barracouta between March 1984 and January 1987 using yellow lock-on spaghetti tags. Fish were line captured by targeting schools close to shore (about 15 n.m.) and in waters predominantly less than 50 m deep. Measurement of individual fish lengths was not possible due to issues of scale loss. Most fish were tagged at Kaikoura and Dunedin. As of June 1988, 42 returns had been made (approximately 1%). The Bay of Plenty had the highest return rate at 4.5% (9/199), with the longest overall time at liberty for an individual fish of 398 days (1.09 years). One fish moved 150 n.m. to the south, while the remaining 8 fish moved less than 75 n.m. In the South Island, 33 of 37 fish recaptured had associated location data; 13 moved less than 100 n.m., 8 between 100 and 200 n.m., and 8 from 200 to 500 n.m. The greatest distance travelled was 500 n.m. over 188 days. Most of the recovered South Island fish had moved north (17 fish), with 10 fish being recaptured near (within 50 n.m. of) their tagging sites, and 2 moving south. Ten fish moved from the South to the North Island, with two individuals moving from the east to the west coast. There were no recaptures from the west coast South Island, south of Stewart Island, or from the Chatham Islands. Of the 10 fish moving between the South and North Island, 8 had known recapture dates – all fell within the July to September spawning period. Conversely, only 2 of the 13 fish moving less than 100 n.m. were recaptured in this spawning period, with most being caught October–April.

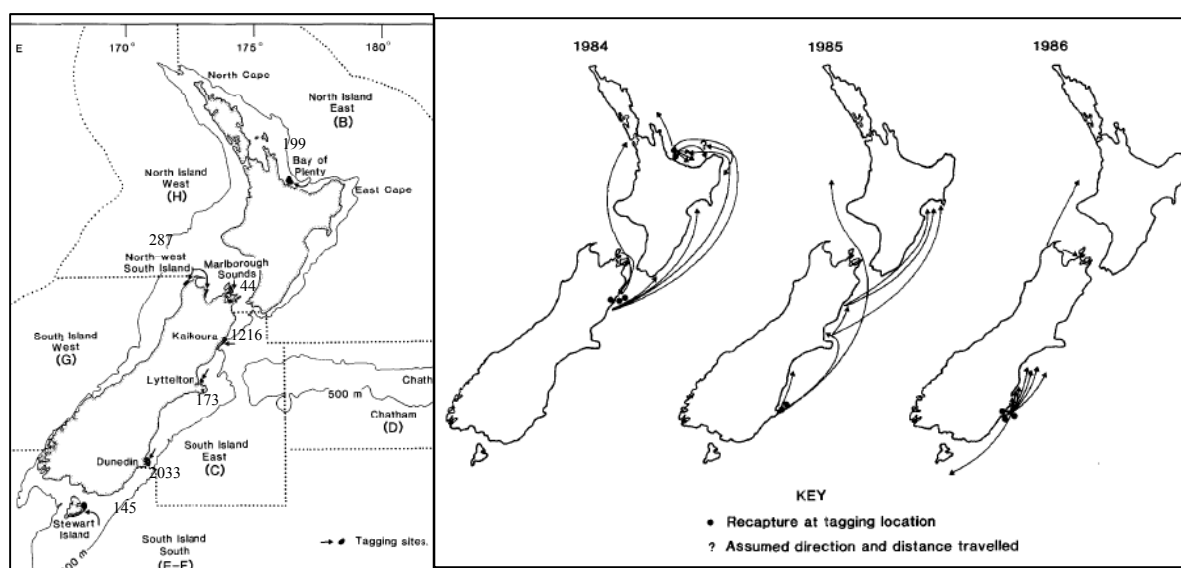


Figure 4: a) Location of tagging sites, and number of barracouta tagged, b) tagged fish movement (assuming minimum possible movement distance), by year of tagging. Four fish had no location data. (Source: Hurst & Bagley 1989, reproduced with permission).

Barracouta movements matched fisheries targeting patterns, with the main commercial fishery for barracouta on the east coast of the South occurring from October to May, as opposed to July to October for the west and east coasts of the North Island, when fish were actively spawning (i.e. a seasonal spawning migration between the two areas). No tagged fish were returned from the west coast of the South Island (none tagged there either), implying “*the possible existence of a predominantly separate spawning group in this region*” (Hurst & Bagley 1989). It was noted that only one Southland tag had been returned and that relative abundance trawl surveys in that southern New Zealand region suggested large-scale migration of fish out of that area between June and November, presumably to spawn. It was also noted that the lack of east coast South Island tag returns from the more southern East Coast did not necessarily reflect minimal movement to that area, as most of the fishery there was by foreign crewed vessels (who did not return tags). No tags were returned from the Chatham Islands, which at that time was also largely fished by foreign-crewed vessels. Previous work by Hurst & Bagley (1987) suggests that these areas may be a separate stock, given a significantly smaller population size structure, unusual issues with annual check rings in otoliths, higher parasite loads (*Anisakis simplex*), and a later spawning season (November/December).

More recent work in South Africa, using a range of catch and other data sources, concluded that spawning there occurs during winter–spring, in waters ranging from 150–400 m deep along the shelf break along the western Agulhas Bank and the South African west coast (Griffiths 2002). Prevailing currents subsequently transport the eggs and larvae to a primary nursery ground (north of Cape Columbine) and a lesser secondary nursery ground (east of Danger Point) – both shallower than 150 m. Juveniles remain within these nurseries until maturity, with their distribution in this depth range determined largely by prey availability, including a seasonal (autumn) migration inshore to utilise clupeoid recruitment. Adults occur throughout the general distribution range of the species, and aside from spawning migrations, which involve some southwards dispersion; long-shore movement appears random with no seasonal influences (Griffiths 2002). Based on spatial differences in sex ratios and prey abundance indices, it was suggested that females on the west South African coast moved inshore to feed between spawning events, but females further south along with western Agulhas Bank remained on the spawning ground throughout the spawning season. This difference in behaviour was attributed to higher offshore abundance of clupeid prey in the latter area (Griffiths 2002).

Population connectivity

Langley & Bentley (2002) examined the possible stock structure of barracouta using commercial catch and effort data, length frequency data from the commercial fishery, and indices of relative abundance and composition from trawl surveys. They were unable to make definitive conclusions on stock boundaries, but qualitatively suggested that there were distinctions between the east coast of the North and South Islands (BAR 1), and the west coast of the North and South Island (BAR 7). Some degree of mixing between these areas due to spawning activity was noted, based on the movement of tagged fish from the east coast South Island to the west coast North Island (Hurst & Bagley 1989). Barracouta were noted to spawn in the Southland area (BAR 5), with a possible associated discrete stock. However, some strong similarities between BAR 1 and BAR 5 were proposed to be due to fish from BAR 1 migrating south into BAR 5 during the summer to feed.

Collectively, in the New Zealand context, the work by Hurst & Bagley (1989), combined with the results of other research and commercial data (Langley & Bentley 2002), suggests the existence of at least three separate barracouta spawning stocks in New Zealand: the east coast North and South Islands; west coast South Island; and the Chatham Islands. The relationship of west coast North Island and southern South Island barracouta to these suggested stocks is unclear.

To conclude, barracouta undertake large scale seasonal spawning migrations, and are present around the mainland of New Zealand, and the Chatham Islands. Oceanographic structuring is likely to be important, although no information was available in the New Zealand context.

3.3 Blue cod (*Parapercis colias*)

Fisheries catch:

Commercial: 2342 t¹

Recreational: 706–1681 t^{1*}

Sexual maturity:

Northland: 10–19 cm / 2 years¹

Marlborough Sounds: 21–26 cm / 3–6 years¹

Southland: 26–28 cm / 4–5 years¹

Maximum age: 32 years¹

Pelagic phase duration:

Eggs: 5 days¹

Larvae: 5 days¹



Photo credit: Malcolm Francis

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; * Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates.

Blue cod are endemic to New Zealand, and occur around the country, but are most common in Southland and around the Chatham Islands (Armitage et al. 1994, McGregor 1988, Beentjes & Carbines 2005). They are opportunistic carnivores (Jiang & Carbines 2002) found mainly on light foul (reef edges, shingle/gravel, and biogenic structures) or sand close to rocky outcrops shallower than 150 m (Mutch 1983, Anderson et al. 1998, Carbines & McKenzie 2004). Diet appears to vary with time and space, driven by what food sources are available in local habitats. For example: Graham (1939a) recorded a diet of crustaceans, fish and molluscs in Otago Harbour and the adjacent sea; Rapson (1956) found Cook Strait fish to have a diet dominated by pelagic fish (pilchards and sprats) and Chatham Island fish to consume principally octopus and fish; Mutch (1983) found east Northland fish to change diet with size, with juveniles feeding mainly on crustaceans (amphipods and isopods), and adults on crabs and ophiuroids (brittle-stars); while Jiang & Carbines (2002) found blue cod diet in Foveaux Strait to be dominated by crustaceans (mainly crabs).

Spawning

Blue cod are non-obligatory protogynous hermaphrodites that spawn from late winter to spring, with the gonadosomatic index (GSI) peaking in September in both Northland and Southland (Pankhurst & Conroy 1987, Carbines 1998, Carbines 2001). Individual fish are involved in multiple spawning episodes (Pankhurst & Conroy 1987), with spawning aggregations having been reported from both inshore and mid-shelf waters (Hurst et al. 2000a). Pankhurst & Kime (1991) sampled milt from male blue cod in situ during the east Northland breeding season (through divers hooking fish underwater and collecting milt samples with needles) and assessed the acute reproductive condition (i.e. the degree of sperm initiation) through the forced emission of milt. Eighty-two fish were sampled over a 10 week period (13 sampling events). Most un-spermiated fish were caught before 1000 hours, while most spermiated fish were captured after 1500 hours. This suggested that spawning occurred in the late afternoon or early evening (although spawning was not observed) and that fish spawned locally on or adjacent to the reef system.

In contrast, Graham (1939b) reported the departure of ripe fish from the coastal Otago region in June, with the subsequent return of spent fish in September. However, running ripe fish have been encountered throughout the Marlborough Sounds (Blackwell 1998), and they are considered to spawn locally in this area (Rapson 1956). However, there have been unconfirmed reports of large migrating or breeding shoals (Mace & Johnston 1983). Robertson (1973) mapped the spatial and seasonal distribution of blue cod eggs in Otago continental shelf waters and concluded that fish spawned in late winter/early summer, with the egg distribution suggesting an adult spawning migration from inshore to deep water. Blue cod are rusty brown as juveniles up to 25 cm in length, after which they change colour to iridescent grey or green and finally to deep blue on the back when longer than 35 cm. Blue cod are not sexually dimorphic.

Egg and larval transport

Eggs and larvae have been recorded from both inner (Parsons 1999) and outer (Robertson 1975, 1980b) shelf waters off Otago. Eggs are pelagic for around 5 days, as are the larvae (McGregor 1988), with young fish appearing on shallow reefs in summer (Paul 2000).

Nursery habitats

Very small blue cod are rarely observed. They are thought to be associated with biogenic habitats such as bryozoans (e.g. Vooren 1975), with small fish also being captured and photographed on the Otago coast bryozoans (Jones & Morrison, unpubl. data). The juvenile ecology of blue cod (less than about 10 cm) is poorly known, as they are not encountered very often during surveys and observational work. Those that are seen appear to be mainly found at the bottom of reef systems, at the general interface between the reef and surrounding sediments. In the Marlborough Sounds, they have been observed to appear at a size of about 5–6 cm on cobble-sand-shell substrate, usually at the foot of cobble banks; and seem widespread, with particular sites apparently supporting higher numbers (R. Davidson, pers. comm). These transitional habitats, depending on region, may be composed of cobbles, large shell litter (including dog cockles), low relief bryozoan clumps, turfing algae, low density horse mussels, and other low relief components. One possible explanation for the constantly low numbers of fish less than 10 cm seen on the reefs proper may be that larvae initially recruit ‘off-reef’ or on the reef boundary in deeper water, and then display an ontogenetic shift onto the reef proper as they grow in size and age. Rapson (1956) suggested that in some areas juveniles are thought to migrate from shelf waters to shallow inshore.

Adult habitats

Blue cod habitats within the Marlborough Sounds are generally composed of relatively homogeneous rock rubble reef dominated by cobbles and small boulders (rubble bank), interspersed with broken shell, sand and silt. These rubble banks extend to approximately 18–22 m depth, beyond which broken and dead whole shell and soft substrata occur. The depth ranges of these sediments and reefs overlap, but the general trend is for an increased proportion of sandy and silty substrata with increasing depth (Villouta et al., pers. comm., via R. Cole, NIWA). The reefs are relatively steep, and extend from approximately 40–80 m offshore.

Large male blue cod can be territorial, holding large and rather loose territories (Mutch 1983). In Northland, Mutch (1983) observed the territories of large dominant males (about 1000 m²) often encompassing those of three to five smaller females (about 250 m²).

Carbines & Cole (2009) used dropped underwater video (DUV) to assess the demersal fish assemblages of two adjacent sites in Foveaux Strait, both of similar mixtures of sand and gravel substratum, one not fished for 7 years (‘recovering’), the other recently dredged for oysters. Video

transects were run over these two sites, and all fish seen counted, with blue cod being assigned to one of three colour phases (being juvenile phase under 15 cm fork length, brown phase 15–25 cm, blue phase over 25 cm). Seven demersal fish species were seen on the recovering site in summer (172 fish, mean density 5.20 ± 0.91 per 100 m², 81% blue cod), while only one species (dogfish, *S. acanthias*) was seen on the recently dredged site (5 fish, 0.16 ± 0.03 per 100 m²). In autumn, four demersal fish species were seen on the recovering site (153 fish, 3.78 ± 0.91 per 100 m², 80% blue cod), and three species on the recently dredged site (27 fish, 0.76 ± 0.21 per 100 m², 89% *S. acanthias*). Habitat effects were significant for brown phase, blue phase, and total blue cod. Comparisons between fish and habitat variables found sponge cover to be significantly positively correlated to all of the three colour phases of blue cod. Topographic complexity, general epifauna cover, and macro-algae cover also correlated significantly with brown and blue phase blue cod. CAP analyses indicated strong dredging effects on benthic habitat (as measured by topographic complexity, general epifaunal cover, sponge cover, and cover of small brown macro-algae) and fish abundance (brown, blue, and total blue cod). The authors suggested that the mechanism impacting on blue cod numbers was increased mortality (i.e., predation) due to less shelter and resources being provided by the reduced benthic habitat complexity; a finding common to a number of fish-habitat studies (Connell & Jones 1991, Gotceitas et al. 1995, 1997, Tupper & Boutilier 1995, Lindholm et al. 1999; Johnson 2006). It was also noted that this pattern of mortality had also been observed for 0+ cod in an aquarium tank experiment (G. Carbines, unpubl. data). Overall, biogenic reefs in Foveaux Strait were concluded to be an important habitat for demersal fishes (in particular blue cod), and deserving of protection in management measures (Carbines & Cole 2009).

Adult migrations and movements

Rapson (1956) tagged blue cod in the Marlborough Sounds, and found that of 191 tag returns, 9.3% had moved more than 1.6 km, and 3.1% had moved more than 16 km. Mace & Johnston (1983, see Figure 5) tagged 2430 blue cod in the Marlborough Sounds between 1973 and 1976. Eighty-four tags (3.5%) were returned, with a median time at liberty of 138 days. Most (71.6%) did not move any significant distance (i.e. they were caught approximately where they were tagged), the remaining 21 fish moved up to a maximum of 41.7 km, with a mean distance of 7.6 km. Of note, on several different occasions up to 8 fish tagged in the same batch were later caught by a single fishing party over one day in the area where they were tagged, indicating clumping of tagged fish. No fish over 30 cm moved any significant distance, which differed from Rapson's study where 16 of the 18 fish moving larger distances were over 30 cm. Rapson wrote that blue cod "*remain on the small fish grounds (areas such as the Trio Islands, D'Urville Peninsula and inside the Sounds) until their sixth to eighth year (corresponding to a size of about 31–37 cm), when they are forced to leave through being deprived of food by the more agile immigrants*" (as highlighted by Mace & Johnston 1983). However, Mace & Johnston reported that smaller fish (19–29 cm) made all of the longer distance movements recorded. They also noted that "*It is widely accepted that blue cod make mass migrations from time to time*", although no supporting evidence was given: this statement has made its way into common acceptance in subsequent years, and appears to have come from anecdotal accounts (LEK). Fishermen (C. Jacobson, C. Guard, pers. comm., in Mace & Johnston 1983) have reported concentrations of ripe blue cod on the banks around the Trio Islands during the spawning season, with Rapson (1956) finding the greatest densities of blue cod eggs in this area. Mace & Johnston (1983) concluded that in their study region, blue cod living around the reefs and rocky coastlines spawn without making any significant migration, but in some areas, especially the banks around the Trio Islands, blue cod may concentrate to spawn. Rapson (1956) also reported on the existence of blue cod in the D'Urville Island area forming "*feeding shoals*", which stayed in one place for short time periods, or moved rapidly following pelagic food concentrations (e.g. ctenophores (comb jellies),

tunicates, and clupeoid fish). Tag returns from these shoal fish however did not indicate any significant movement. Mace & Johnston (1983) concluded that while there was no empirical evidence for migratory feeding shoals, it could not be discounted, as blue cod further offshore, including those associated with foul ground such as bryozoan corals, had not been tagged. Overall, they concluded that blue cod in the Marlborough Sounds and adjacent coastal islands belonged to one stock, which was largely resident over time, although some fish moved significant distances.

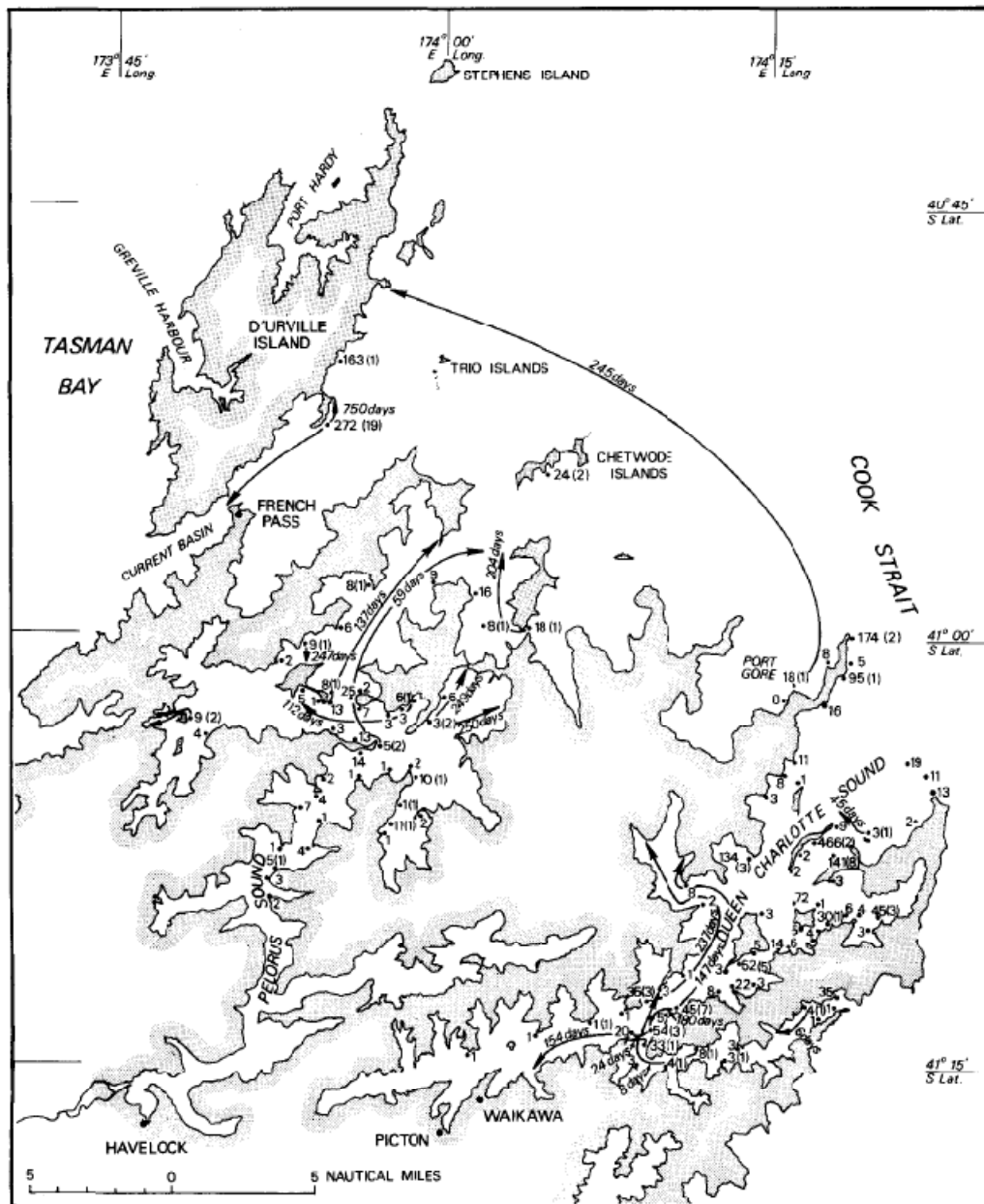


Figure 5: Tagging and recapture sites and inferred movements of blue cod (*Parapercis colias*) in the Marlborough Sounds. Tag releases (un-bracketed figures), tag recaptures (bracketed figures). Arrows show inferred movement of individual fish (Source: figure 1 of Mace & Johnston 1983, reproduced with permission).

Cole et al. (2000) used external tags and visual resightings by divers to look at ‘spill-over’ from the Long Island–Kokomohua Marine Reserve in the Marlborough Sounds (2 reserve and 2 non-reserve sites, each with 90 tagged fish, 16 surveys over 377 days, maximum distance from tag sites searched

about 1 km). Most blue cod resightings (n=89) were made within 100 m of where a given fish was tagged (75% reserve, 73% non-reserve sites), with resights declining through time. It was suggested that smaller adult fish moved greater distances, with five of six fish moving more than 250 m inside the reserve (9% reserve resights) estimated to be in the 240–290 mm size range, as was the one fish outside the reserve that also dispersed a longer distance (maximum distance detectable being one kilometre) (0.6% non-reserve resights). All fish larger than 350 mm resighted were within 150 m of their release site, and it was suggested by the authors that larger blue cod were home-ranging in Queen Charlotte Sound. Overall they concluded that the data pointed to limited dispersal, with blue cod growing to larger sizes in the reserve, and providing a fisheries spillover function for adjacent areas of rocky coastline, but at relatively low levels.

Carbines & McKenzie (2001) tagged over 9500 blue cod across Foveaux Strait, with 8% being recovered over a 20 month period. The median distance moved was 800 m, with 60% moving less than 1 km, and a strong trend of westwards movements counter to the prevailing water current, i.e. 'up-stream'. The greatest distance moved was 156 km. A proportional mixing model estimated moderate mixing across broader scale strata (7.3% and 14.7% over the 20 month period for neighbouring fisheries areas 027 and 030 in BCO 5). However, at finer spatial scales mixing rates were much higher among the 14 tagging strata (mean extent of 312 km²), ranging up to 44%. It was concluded that Southland blue cod form relatively discrete stocks at scales below that of fisheries statistical reporting areas (which are about 1000 km²), and as such were vulnerable to localised depletion.

Carbines & McKenzie (2004) tagged 4077 blue cod across 115 sites in Dusky Sound, Fiordland, across five spatial strata. Over the subsequent 17 months 219 tags were returned, of which 86 had sufficient associated information to assess movement. Sixty-five percent of fish moved less than 1 km from their release site, while larger movements were generally eastwards further into the fiord. A formal fisheries-independent recovery phase was undertaken one year after tagging across 41 sites, with 61 tagged fish being recaptured. Using a proportional mixing model, the two outer Dusky Sound strata contributed 7.4% (0.1–23.2) and 9.2% (0.1–26.1) respectively of their populations into the inner half of the fiord, which maintained 100% residency. This was interpreted as a source-sink dynamic. Larger distance movements included four fish moving over 20 km, including two recaptured in Chalky Inlet to the north, more than 30 km by sea.


Beer et al. (2011) used otolith chemistry (from the outermost edge of otoliths) to further investigate differences between five inner and outer fiord areas in southern Fiordland. Blue cod in the inner fiords had more discrete signatures, attributed to either isolation or distinct physico-chemical conditions in each fiord. Signatures differed between inner and outer fiord blue cod subpopulations in Bradshaw-Thompson, Breaksea and Dusky Sounds, but not in Doubtful Sound or Long Sound-Preservation Inlet. For the latter location, the lack of discrimination was attributed to the relatively sheltered outer fiord area being atypically estuarine in nature (see Wing et al. 2003, N. Beer & S. Wing unpubl.), rather than extensive mixing of blue cod, given larger differences in population and growth rates between the two areas (N. Beer & S. Wing unpubl.). Lower reclassification success rates among outer fiord subpopulations were postulated to reflect population mixing or the more dynamic environment of the exposed coastal habitat. A fish translocation experiment in Doubtful Sound found that fish gradually changed their otolith elemental signature towards the area of release. This study concluded that otolith chemistry showed that there was only limited mixing between inner and outer fiords over time scales of weeks to months, consistent with early mark-recapture (Carbines & McKenzie 2004), and stable isotope work (Rodgers & Wing 2008, Beer 2011), demonstrating distinct spatial structuring of blue cod populations in Fiordland.

Pande et al. (2008) undertook a meta-analysis of marine reserve effects on blue cod in New Zealand, and found that blue cod were bigger inside marine reserves than outside for 9 of 10 studies, and more abundant inside marine reserves in 8 of 10 studies. These findings strongly imply local residency in some significant proportion of the blue cod populations involved.

Population connectivity

There is little information on broader scale connectivities, beyond the tagging studies discussed above. Based on the work in Fiordland and Foveaux Strait, blue cod populations are thought to be spatially structured at the tens of kilometres scale, much less than the scale of fisheries statistical reporting areas.

3.4 Blue mackerel (*Scomber australasicus*)

<p>Fisheries catch: Commercial: 8638 t¹ Recreational: 35–90 t per year for EMA 1, insignificant for other areas^{2*}</p> <p>Sexual maturity: Males: 23.6 cm (Australia)³, Females: 28.7 cm (Australia)³ / 2 years.</p> <p>Maximum age: 24 years (Bay of Plenty)²</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: 35 days</p>	
<p>¹MPI web site - for the 12 month period to 30/09/2011; ²MPI Assessment Plenary Document, Part 1, 2012; ³See Plenary document for caveats around these estimates; ³Rogers et al. (2009)</p>	

Blue mackerel are a pelagic species, and have a broad geographic range, occurring across the Indo-West Pacific, in the Red Sea and Persian Gulf, around Japan, in the eastern Pacific, including Hawaii and off Mexico (Sorocco Island), and around Australia and New Zealand (FishBase 2012). Dietary work in New South Wales classified adults as pelagic omnivores, eating mostly pelagic invertebrates such as ascidians, pyrosomes and salps, along with fish (less than 40% of its diet) (Bulman et al. 2001).

Spawning

Taylor (2002) states that blue mackerel spawn from November to April, with associated water temperatures of 15 to 23° C (Crossland 1981a). Ripe, running ripe and spent fish have been recorded from a few tows off Tasman Bay and Taranaki (Hurst et al. 2000a). Rodgers et al. (2009) looked at the reproductive biology of blue mackerel off southern and eastern Australia, as part of an assessment of the suitability of the Daily Egg Production Method (DEPM) for future stock assessment. They reported blue mackerel to be serial spawners with asynchronous oocyte development and indeterminate fecundity. Spawning off southern Australia occurred between November and April, and off eastern Australia between July and October. In southern Australia, about 50% of males and females were mature at 236 and 287 mm fork length (FL), respectively, while the size at maturity in eastern Australia could not be reliably estimated.

Egg and larval transport

Roper (1986) used a cone net (0.45 mm) from a moored boat to sample neustonic (in the surface layer of the ocean) fish larvae as they were transported by the tidal stream in and out of a small estuary

(Whangateau), on the east coast, western Hauraki Gulf. Sampling on a frequent basis over a year, he recorded larval blue mackerel in two summer sampling events (January-February). Densities were low compared to other species (0.3 individuals per 100 m³). Tricklebank et al. (1992) sampled further offshore in the same coastal zone as Roper (1986), using a towed 1 × 1 meter net with 1 mm mesh. Ninety five blue mackerel larvae were sampled, occurring across 8.6% of the tows. These tows fell in the months of November (1986, 1987), and January–June (1987). However, Kingsford & Choat (1989), using the same net as Tricklebank et al. (1992) and sampling more broadly across the Hauraki Gulf (October–January 1984), did not report any blue mackerel larvae. In a general review of early life histories of fish in New Zealand, Kingsford (1988) found no predictable pattern in abundance of blue mackerel larvae with respect to distance from land (but note that this covered only the north-western Hauraki Gulf).

Neira & Keane (2008) undertook three ichthyoplankton surveys along the south-eastern Australia coast (860 n.m.) from southern Queensland (24.6° S) to southern New South Wales (41.7° S), to quantify the spawning habitat and dynamics of blue mackerel. These surveys were carried out in October 2002 and 2003 (spring), and July 2004 (winter), and focussed mainly on the outer shelf, including the shelf break. Eggs and larvae occurred in both seasons, but were geographically confined from 25° to 34.6° S, with the greatest abundances within 10 n.m. shoreward of the shelf break in northern New South Wales. Analysis of egg abundance patterns found that spawning dynamics were closely linked to a combination of bathymetry and hydrographic influences, with the preferred spawning area being the outer shelf, in waters 100–125 deep, and mean water temperatures of 19–20° C. Eggs and larvae in the spring were located in waters of the East Australian Current (EAC, 20.6–22.3° C), and adjacent ‘mixed’ waters (18.5–19.8° C), while none were found further south in the Tasman Sea water mass (16.0–17.0° C). Spawning was linked to the EAC intrusion, which, it was suggested, facilitated the southwards transport of eggs and larvae. Neira & Keane (2008) concluded that their ichthyoplankton-based results “*provide persuasive evidence of a close link between the spawning dynamics of blue mackerel during winter–spring, and the EAC flow path along eastern Australia and subsequent interaction with shelf waters*”. It was suggested that this link included the components of (1) suitably warm temperatures for spawning and development of the pelagic eggs and larvae; (2) a spawning area whose southern limit is restricted by the extent of the EAC incursion over the shelf; (3) spawning ‘hotspots’ in shelf areas where the eastward deflection of the main EAC flow triggers upwelling of nutrient-rich water; (4) the along-shelf southward advection of eggs and larvae; and (5) the across-shelf eastward advection of spawning products along the EAC deflection front. The interface between the mixed and Tasman water masses also coincided almost exactly with the southern limit of blue mackerel larvae, and it was suggested that it acted as a barrier to the southward dispersal of larvae. Neira & Keane (2008) concluded that their data did not support a hypothesis of seasonal spawning migrations (either partial or full) north into southern Queensland by the south-eastern blue mackerel stock. Rather, they strongly suggested that spawning dynamics of blue mackerel were closely linked to the EAC incursion, both in terms of suitable water temperatures for spawning and development of eggs and larvae, and southward transport. The likelihood of advection offshore (eastwards) along the EAC deflection front also raised the possibility of the Tasman Front acting as an ‘open-sea early nursery area’, where entrained larvae take advantage of conditions which favour high survival and growth rates.

Condie et al. (2011) developed a particle transport model to examine how the EAC (and the Leeuwin Current, South Australia) influenced local retention and cross-shore transport of small larval pelagic fish in the upper water column. The EAC was observed to form a partial barrier to onshore transport, but was effective in entraining shelf waters and transporting particles off-shore, in particular in the

region where the current separated from the shelf. Interpreting their model results in the context of the blue mackerel spawning dynamics suggested by Neira & Keene (2008), they concluded that “*this particular spawning area provides the most effective offshore transport and dispersion of any region around Australia*”, allowing larvae to be transported eastwards towards New Zealand across a 10° latitudinal band centred on the Tasman Front. It was argued that this was consistent with the high catches of blue mackerel larvae recorded in the Tasman Front (Neira & Keene 2008), and the genetic homogeneity of eastern Australian and New Zealand blue mackerel stocks (Scoles et al. 1998). While the larval duration of blue mackerel was stated to be unknown, the strong (although unstated) inference was that larval transport extends across the Tasman Sea to New Zealand. They hypothesised that the general oligotrophic environment of the EAC favoured blue mackerel larvae, acting to disperse them widely to locate limited resources, so that a significant proportion of larvae would be entrained into the more productive patches of the EAC eddy field, including the centre of upwelling cyclonic eddies, and/or the periphery of convergent anticyclone eddies. The latter dominate the EAC system, it is suggested that they help capture, concentrate and retain larvae, forming ‘effective ocean triads’ within areas of this otherwise oligotrophic environment (*sensu* Bakun 1996).

Roughan et al. (2011) further investigated the impact of the circulation of the EAC on larval transport patterns, using a series of Lagrangian particle trajectory simulations, for winter and summer periods, encompassing the years 1992 to 2006, along with an estimation of a ‘mean connectivity state’. The movement of five individual larval species, including blue mackerel, was estimated by releasing particles to mimic likely timing and location of the spawning populations. Blue mackerel larvae were released at sites in 100 and 200 m water depth, in winter, at the shelf break. The 100 m depth in winter was the most successful of all the across-shelf sites tested in general, with 30% of sites being connected in the first 30 days post-release. The 200 m sites were less successful. More generally, the EAC was found to act as a barrier to the onshore movement of particles starting offshore, affecting the connectivity of offshore sites. Particles released inshore of the EAC jet had a greater coastal connectivity. The separation point of the EAC also dictated connectivity, with more sites being connected (with an associated lower concentration of particles) downstream of the separation point of the EAC.

Work on blue mackerel off north-eastern Taiwan found high abundances of larvae between February and March in the shelf break region of the southern East China Sea (ECS), with the under 5 mm size of the larvae (less than 10 days old) suggesting that this was also the approximate area of the spawning ground (Sassa & Tsukamoto 2010). Associated water temperatures were 20 to 23° C, with the authors suggesting that the contrast with Neira & Keene’s (2008) recorded temperatures of 17.5 to 20.5°C indicated varying optimal temperatures between different populations. Observations across two years found that in 2004, blue mackerel were transported north-eastward in association with an intrusion of the warm Kuroshio Branch Current north of Taiwan (KBCNT), while in 2005, when the branch current was weak, they dispersed eastwards along the Kuroshio Front. Particle-tracking models of these two differing routes of larval transport from the spawning ground showed that for the former process, over a period of 17 to 30 days, a high percentage of larvae would recruit into the shelf regions of the ECS, while those for the latter process would reach the Pacific Ocean off the coast of southern Japan (Kasai et al. 2008). Sassa & Tsukamoto (2010) noted that the current features in the ECS were highly variable and complex due to the relative strength of the Kuroshio Current, tidal currents, and mesoscale frontal disturbances. This in turn was likely to result in fluctuations in larval transport processes over relatively short periods. Blue mackerel grew significantly faster in 2004 than 2005, which was attributed to higher zooplankton abundances (food productivity) in 2004, which in turn was linked to the presence of a permanent up-welling system at the shelf break north of Taiwan.

This nutrient-enriched upwelling is directed northwards with the intrusion of the KBCNT, enhancing pelagic productivity. A frontal structure also forms between the Kuroshio Current and coastal waters, which allows for the mixed layer depth to become relatively shallow, with high water stability due to the development of a pycnocline, with the two interacting to increase phytoplankton production (Nakata et al. 2007, cited in Sassa & Tsukamoto 2010). As well as the higher larval growth seen in 2004, subsequent analyses of recruitment success, expressed as recruit per spawner, for 0+ blue mackerel in the ECS and the western Japan Sea, was calculated to be 2.3 times higher in 2004 than in 2005 (Fisheries Agency and Fisheries Research Agency of Japan 2010, cited in Sassa & Tsukamoto 2010). Such relationships were suggested to help explain the annual recruitment variation of blue mackerel in the ECS.

Nursery habitats

Fish less than 29 cm in length occur in shallower waters (less than 100 m) inshore areas around the northern North Island and in Tasman Bay, while larger juveniles up to 39 cm have a similar distribution which extends into slightly deeper water (note that size at sexual maturity, and the length composition of Australian populations appear to be substantially less than New Zealand populations). Juveniles have not been sampled in any great abundance, with the one large catch of 360 kg.km⁻² being recorded from the outer Hauraki Gulf (Hurst et al. 2000a). Anecdotal evidence from recreational fishers suggests that juveniles are seasonally abundant in inshore waters, while larger fish occur further offshore.

Adult habitats

In New Zealand, blue mackerel are predominantly caught around the North Island by commercial fisheries and in research surveys, but their distribution extends down the east and west coasts of the South Island. They are rarely caught in Southland or on the Chatham Rise (Anderson et al. 1998). The principal fisheries are a northern New Zealand purse seine fishery, in particular in the Bay of Plenty and east Northland from July to December, and a significant by-catch as part of the jack mackerel trawl fishery in the Challenger region (Morrison et al. 2001b).

Adult migrations and movements

Unknown

Population connectivity

Smith et al. (2005) assessed available evidence for stock areas in New Zealand blue mackerel, using samples of whole fish collected from EMA 1, 2 and 7 in 2002, along with a small 'out-group' sample from New South Wales. These groups were assessed using meristics, genetics, and parasites. They found significant differences in the characters of number of gill rakers, and the number of fin rays in the pectoral, first dorsal, and second dorsal fins respectively. A fragment of the mitochondrial DNA control region was sequenced in 60 specimens and revealed high haplotype diversity, with two genetic lineages being apparent. However, this did not show any clear geographic structuring, with individuals from each lineage being found in the EMA 1, EMA 2, and New South Wales groups. Seven parasites were found associated with blue mackerel, of which two appeared useful as markers. The acanthocephalan *Rhadinorhynchus* sp. (a gut parasite) showed significant differences between EMA 1 and EMA 2, while larval *Anisakis* sp. (a nematode worm occurring in the gut) showed significant differences between EMA 1 and EMA 2, and EMA 2 and EMA 7. Based on these findings, Smith et al. (2006) suggested that blue mackerel in New Zealand were divided into at least three stocks in EMA 1, EMA 2, and EMA 7.

To conclude, blue mackerel are a warmer water species in the New Zealand context, occurring in greatest abundances across the northern half of New Zealand, but aside from catch sampling and associated assessment of growth structures and age frequencies (from the purse seine fishery), little life history information is available. Based on Australian and East China Sea work, it is likely that oceanographic processes may be very important for New Zealand populations, but there is no data with which to test such possibilities at present.

3.5 Blue moki (*Latridopsis ciliaris*)

Fisheries catch:

Commercial 574 t¹

Recreational 117–245 t^{1*}

Sexual maturity: 40 cm / 5–6 years²

Maximum age: 43 years / about 80 cm³

Pelagic phase duration:

Eggs: Unknown

Larvae: Paper-fish 8–12 months⁴

Key areas: East Cape: there is a net exclusion zone within a two nautical-mile wide coastal band beginning at the high water mark and extending from Cape Runaway to a stream tributary at Oruiti Beach, trawling, Danish seining and set-netting prohibited.



Photo credit: M. Francis

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; * Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²Francis (1981a); ³Manning et al. (2009); ⁴Francis (2001)

Blue moki are endemic to New Zealand waters. Blue moki recruit periodically across the Tasman Sea into southern Australian waters (Yearsley et al. 1999), with confirmed reports of frequent juveniles in the late 1980s off eastern Tasmania, which then disappeared. Last et al. (2011) also list blue moki as a periodical resident in Tasmania. Adults consume crabs, other crustaceans, shellfish and worms (Francis 2001).

Spawning

The main spawning area (thought to be the only one) is off the East Cape region.

Egg and larval transport

Francis (1981a) speculated that eggs spawned near Gisborne would be carried southwards by the East Cape Current (Heath 1972), which would explain the absence of juveniles north of East Cape (Doak 1972). The East Cape current flows eastwards towards the Chatham Islands when it reaches the Wellington region, although Francis also noted that branches of the current frequently upwelled in the Cook Strait and Kaikoura regions (Garner 1953, Heath 1971, 1972), which might return larvae to the coast. However, blue moki, as with other moki species, have a pelagic paper fish phase (see tarakihi section for a more detailed description of this phase), which if similar to tarakihi may last 8–12 months (Francis 2001). Paper fish may reach sizes of up to 10 cm before settlement to the seafloor, allowing for significant dispersal through both oceanographic processes and active swimming.

Nursery habitats

Blue moki juveniles are mainly observed on shallow rocky reef systems between East Cape and Stewart Island, and eat small crustaceans associated with seaweed (Francis 2001). Ayling & Cox (1987) report juveniles (“*young fishes*”) as being “*frequently seen from Cook Strait southwards, usually swimming near the bottom in large groups*”. No juveniles of less than 30 cm have been recorded north of East Cape (Francis 2001).

Adult habitats

The main distribution of blue moki is along the east coast of the North and South Islands, to a maximum depth of 250 m; they also occur sporadically on the west coast of both islands (Anderson et al. 1998). They are also found at the Kermadec Islands (rare), Three Kings Islands (common), and at the Snares and Auckland Islands (Francis 2001). Adults occur over sand and mud bottoms, as well as reefs.

Adult migrations and movements

To assess the hypothesis that adult blue moki made a seasonal migration north to East Cape for spawning and then south again each year, Francis (1981b) used several lines of evidence to convincingly argue for blue moki migration (locally known as ‘moki runs’). Commercial catches were sampled from four ports down the eastern seaboard (Gisborne, Napier, Wellington and Kaikoura), to assess catch seasonality as a proxy of abundance; and to quantify sex, body and gonad weight, as well as reproductive status for the most northern and southern ports (Gisborne and Kaikoura respectively). Commercial catches (expressed as catch per vessel per month) were highly seasonal, with a spatial pattern in their occurrence – Kaikoura (May/June)→Wellington (May/August*)→Napier (June/July)→Gisborne (Aug/Sept)→Napier (Sept/Oct)→Wellington (Sept/Oct)→Kaikoura (Oct) (*, variable between years, pattern less clear) – which suggested a northern then southern movement each year. As noted by Francis (1981b), these data were subject to bias such as catch under-reporting, effort variation (e.g. due to weather or economics), effort and catch efficiency variation between vessels, inter-annual effort variation, and changes in spatial effort; but nevertheless showed a relatively clear pattern.

Sampled fish at Kaikoura and Gisborne were each assigned a reproductive state: female states were: I, resting; II, developing; III, ripe; or IV, spent; while males as either: I, containing semen in the testes or vas deferentia; or II, not. Kaikoura autumn-run (May/June, presumed heading north pre-spawning) female fish were resting (I), with some developing fish (II) later on, while most males had semen in the vas deferentia, and low gonad indices. Both sexes contained large visceral fat deposits, which often enveloped the gonads and digestive system, along with very oily flesh. In the Gisborne samples, female gonad development moved rapidly through developing (II), ripe (III), and spend stages (IV), with the first ripe fish being captured less than a week after the commencement of the Gisborne run (13th August 1978), while developing fish (sampled 10th September 1978) had gonad indices ranging from 5.51 to 8.78 (index is the ratio of gonad weight to body weight, multiplied by one hundred; note that these fish may have already partially spawned). All of the males sampled (38) had copious quantities of semen. In the Kaikoura spring-run moki (October, presumed heading south post-spawning), all female fish were spent (IV), apart from one ripe (III) female with a low gonad index (1.55). Only one male out of thirty-nine contained semen. Both sexes had virtually no visceral fat, and the flesh was very lean (Francis 1981b).

Francis (1981b) also tagged 191 blue moki at Kaikoura, using plastic lock-on tags inserted just behind the dorsal fin origin. These fish were captured at 80–100 m, 6–28 May 1979. Twenty four recaptures were reported (12.6% return). Twelve of these were made within three weeks of release within the

same local region of release. Of the other twelve, 3 were recaptured between Kaikoura and Gisborne. One was taken 430 km north of Kaikoura, at Post Office Rock, off Napier (July 1979, 65 days after release, minimum average speed 6.6 km/day). Two fish were recaptured off Gisborne: one 540 km north of Kaikoura at The Gables (August 1979, 108 days after release, 5 km/day); the other 570 km north of Kaikoura at South Aerial Rocks (April 1980, 344 days after release, 1.7 km/day). This suggests that the Napier fish was caught during the 'Napier run', and one of the Gisborne fish during the 'Gisborne run', while the other Gisborne fish was taken outside the time of the local run, during a period when overall blue moki catches were low.

Of the other 9 tag recaptures, all were re-captured at Kaikoura; one was recaptured 82 days after release, at the end of the (northwards) run when fish were tagged (May 1979); six were recaptured during the first spring run (Oct/Nov 1979) (southwards return of spawning fish), and two during the subsequent 1980 year autumn run (northwards run, a year later), with a time at liberty of 417 days. Two further fish were reported as the Francis (1981b) paper was in proof. One was visually sighted underwater at Island Bay, Wellington (March 1981), and it was noted that it did not fit into the spawning migration hypothesis, "*indicating that some fish at least drop out of the main migration and disperse in shallow coastal waters*". A second fish was recaptured near Ariel Rocks, Gisborne (August 1981, 815 days at liberty), with its timing of capture fitting the spawning migration hypothesis.


Francis (1981b) concluded that where the moki schools (assuming they remain in schools) went to during the summer season (November–April) following the spawning run was unknown, with the lack of significant commercial catches of blue moki south of Kaikoura (as of up to 1981) being taken as evidence of the main migration not continuing past Banks Peninsula. It was speculated that fish might move into deeper water, or out onto the Mernoo Bank (170 km south-east of Kaikoura, on the Chatham Rise). Wherever they went to, they were "*almost certainly feeding intensively to build up energy reserves for the next annual migration*" (Francis 1981b).

Moki are commercially targeted during the migration 'runs', with specific locations often being fished, representing a movement corridor (migration) for blue moki. Langley & Walker (2004) recorded the following observations from fisher interviews. In the northern QMA 2 fishery, trawlers caught blue moki in shallow waters, but their greatest abundances with depth varied seasonally. It was observed that "*while moki used to travel in large schools over the soft bottom, they are now not so densely aggregated, though the common movement (migration) is still apparent*". Further south, in the Kapiti trawl fishery, trawlers catch moki in around 90 metres water depth, with "*these moki are not thought by the fishers to be migratory even though they do have the white flesh said to be associated with migratory fish on the east coast of New Zealand*". In the target set-net fishery, moki are specifically targeted as they migrate past the Wairarapa Coast, mostly in the north run from May–July, when they are in the best condition (pre-spawning). Migrating fish were stated to have more desirable white flesh, while the resident moki had black streaks in the flesh, and were avoided (Langley & Walker 2004). One fisher from Napier "*does not think that moki are in schools, just going in the same direction, although they may clump as they go over shallow ground*", while others stated that they were caught in mixed schools with tarakihi. Langley & Walker (2004) concluded that: "*there remain a number of other important parameters of the biology of blue moki that need to be determined before a stock assessment could be undertaken. One of the more significant would be to estimate the proportion of the stock that migrates to the spawning ground each year and, conversely, the proportion of the stock resident along the northeast coast throughout the year. These movements would be best investigated with a comprehensive tagging programme of the stock. This would also potentially provide an estimate of current biomass and fishing mortality rates*".

Population connectivity

Francis (1981b) concluded from his various lines of evidence “*the existence of a single moki stock that migrates from the south or south-west of Kaikoura to Gisborne for spawning, and back again, every year*”. He also commented that the concentrations of blue moki found near Cape Runaway (west of East Cape) in June-July (mentioned by Poata (1919), cited in Francis (1981a)), were thought to be migrating fish arriving from the Bay of Plenty to join the spawning schools at Gisborne (K. Walshe, Fisheries Management Division, Tauranga, pers. comm., in Francis 1981b). Collectively, these data show that blue moki is likely to be one large well-connected population in New Zealand, structured at the hundreds to thousands of kilometres scale, although questions remain about west coast and Southland populations. Partial migration is very likely based on the knowledge of fishers, and a limited tagging programme.

3.6 Blue (common) warehou (*Seriolella brama*)

<p>Fisheries catch: Commercial: 2924 t¹ Recreational: 20–30 t^{1*}</p> <p>Sexual maturity: 4–5 years / 37 cm²</p> <p>Maximum age: 23 years / 75 cm^{1,2}</p> <p>Pelagic phase duration: Eggs: 4 days³ Larvae: Unknown</p>	 <p>Image: dpiw.tas.gov.au</p>
<p>¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; * Recreational catch surveys from Central and South regions, 1991–1993; ²Bagley et al. (1998a); ³Robertson (1973)</p>	

Blue warehou are found in shallow to mid-shelf depths (5–400 m) of the South Island and lower North Island, but are most abundant from Cook Strait southwards, with a patchy distribution on the west coast of the North Island, and are uncommon along the east coast of the North Island (McDowall 1982, McMillan et al. 2011). This semi-pelagic species also occurs in southern Australia; from New South Wales to South Australia (McDowall 1982). Blue warehou diet consists of planktonic organisms, mainly salps (*Iasis*) and tunicates (*Pyrosoma*), but also euphausiids (*Nyctiphanes*) and *Munida* (Gavrilov & Markina 1979, Fenaughty & Bagley 1981).

Spawning

Blue warehou are thought to undertake substantial spawning migrations. They are primarily a spring spawner, with a spawning period from late winter through to late summer (Robertson 1980b). Hurst et al. (2000a) summarised the known spawning areas from previous literature and database extracts. Running ripe fish have been recorded in 50–300 m water depth along the west coast of the South Island (a target fishery) from August to September, and east and west of Stewart Island in November (Hurst 1985, Jones 1988); Kaikoura (March–May), the south-east coast of the North Island (including Wellington) in winter-early spring (Bagley et al. 1998a), and Hawke Bay in August and September (Jones 1988, Bagley et al. 1998a). There may also be a north-west population that spawns off New Plymouth in winter-spring (Bagley et al. 1998a). Spawning activity is also known to occur on the east coast from Nugget Point to Castlepoint.

In Australia, blue warehou are known to spawn in winter (i.e. May–August, with spent females evident until November), with regional differences in timing between the two known spawning

grounds (i.e. western Tasmania/Victoria, and NSW/eastern Victoria) (Knuckey & Sivakumaran 2001).

Egg and larval transport

Eggs & larvae have been recorded in surface plankton in central and southern mid-shelf waters in spring to autumn off Otago and Kaikoura (Robertson 1973, 1975, Parsons 1999). Robertson (1973) reported that on two separate occasions in January 1972 when a plankton net was accidentally towed through rafts of drifting seaweed (the giant kelp *Macrocystis pyrifera*), once in Otago Harbour and later off the Otago Peninsula, juveniles of 50–58 mm fork length were captured. In Australia, larvae have been caught from shelf waters near both known spawning areas (Bruce et al. 2001a) and late stage larvae and small juveniles are often associated with flotsam and jelly fish in coastal and estuarine waters (Last et al. 1983, Bruce et al. 2001a).

Nursery habitats

Ayling & Cox (1987) reported that young of the year (0+) fish are often found in small schools in the shallow waters of harbours and bays around most of New Zealand. Hurst et al. (2000a) reported 0+ juveniles as being confined to waters of less than 75 m, around the north of the North Island and Southland, and the west and east coasts of the South Island. They noted that they were absent from the central east coast and Southland, but that this may have been a reflection of there having been little sampling in less than 30 m in these areas. Older juveniles were reported to extend further offshore. Extensive sampling of estuaries across New Zealand has not recorded their presence (Francis et al. 2005, 2011), aside from capture of modest numbers of 200–300 mm (2+) juveniles in winter in the mid-Manukau Harbour (by gill-nets, M. Morrison unpubl. data). However, the national sampling has not included deeper subtidal estuarine areas in central and southern New Zealand.

Trawl survey catches have highlighted areas of higher abundance: catches in Tasman and Golden Bay are generally of small 0+ and 1+ fish (under 30 cm) only, although these are not present in all years; and on the west coast, mainly south of Cape Foulwind in over 100 m water depth, where 1+ juveniles are caught (Stevenson & Hanchet 2000b). An area between Haast and Okarito ('stratum 15') often holds the highest catches.

In the east coast summer trawl series, 0+ (7–13 cm) and 1+ (14–18 cm) fish are caught in depths of less than 30 m, with high catch rates in Pegasus Bay (0.7 t km⁻²). There is some evidence of more than one spawning event in a given survey year (Beentjes & Stevenson 2001). In the North Island, high catch rates of juveniles were recorded in the Bay of Plenty and off Gisborne (0.2 and 0.1 t km⁻² respectively) (Hurst et al. 2000a). In Australia, juvenile blue warehou are often caught by recreational fishers in bays and estuaries (Kailola et al. 1993). Last et al. (1983) and Lyle & Ford (1993) also reported that the bays and estuaries of south-eastern Tasmania were major nursery areas for both species (Bruce et al. 2001b).

Adult habitats

No information was available at finer habitat scales.

Adult migrations and movements

The seasonal patterns of blue warehou landings suggest there is an annual coastal migration for this species (MPI 2012), given the observed patterns of fisheries around the country. There is a winter/spring fishery for blue warehou at New Plymouth and north Wairarapa, a summer fishery with a small autumn peak at Wellington and a summer/autumn fishery along the east coast South Island. The west coast South Island has a fishery in August/September which picks up again in summer.

There is a summer fishery in Tasman Bay. A similar pattern is seen in Australia, with commercial catches peaking during the spawning period, when fish are thought to aggregate, and fishers regularly report the capture of running-ripe fish (Smith 1989, Tilzey 1998). Seasonal catch-rate trends in some regions support a migration probably associated with spawning (Bruce et al. 2001a). Knuckey & Sivakumaran (2001) reported a marked decline in catch rates of blue warehou off south-eastern Tasmania during winter, and suggested that this may indicate a north–south migration; alternatively, these fish may have migrated to primary spawning grounds off the west coast of Tasmania during this period (Bruce et al. 2001b).

In New Zealand, very limited tagging (about 100–150 fish) was undertaken in 1984 in conjunction with barracouta studies, but no returns were made (Jones 1988). No other details of this tagging could be found. Tagging efforts in south-eastern Australia have also been in-conclusive (Knuckey, personal communication, in Bruce et al. 2001b).

Population connectivity

No definite stock boundaries are known for blue warehou in New Zealand. However, Bagley et al. (1998a) reviewed the information on known spawning grounds and seasonal fishing patterns, and suggested that there may be four tentative stocks, as follows: 1) A southern population, mainly off Southland but perhaps extending into the Canterbury Bight. The main spawning time is November in inshore waters east and west of Stewart Island, 2) A central eastern population, located on the northeast coast of the South Island and southeast coast of the North Island (including Wellington), spawning mainly in the northern area in winter/early spring and also in autumn off Kaikoura. 3) A south western population which spawns on the west coast of the South Island in winter. 4) A north western population which may spawn off New Plymouth in winter/spring.

In Australia, Bruce et al. (2001a) suggested that the distribution of larvae, geographically separate spawning areas and known differences in size/age composition indicated two separate populations, east and west of Bass Strait respectively. Subsequent to this, these two presumed stocks are now managed as separate entities (e.g. Punt & Smith 2006). Growth (size at age) of blue warehou differs between east and west of Bass Strait (Punt & Smith 2006), and fish from these two areas also differ significantly in morphology, otolith shape and otolith microchemistry (Talman et al. 2004) (note: the latter study used the same fish as the Robinson et al. 2008 study below).

Robinson et al. (2008) looked at blue warehou genetics across a range of south-western Australian locations, including Tasmania, and found no significant differences after Bonferroni corrections (a correction for multiple comparisons), but commented that differences were apparent before this correction was made for sites between East Tasmania and West Victoria, and northern and southern regions (Bonferroni corrections are known to produce extremely conservative p values). Given this, they warned that caution and further investigation was required in assessing the genetic stock structure of this species.

3.7 Butterfish (*Odax pullus*)

Fisheries catch:

Commercial: 116 t¹

Recreational: 67–180 t^{1*}

Sexual maturity: 95% females mature at 22.9–29.7 cm / 1–2 years in Hauraki Gulf. 50% mature at 25.2 cm / 4 years in Stewart Island^{2,3}



Maximum age: 10 years Northland,
19 years Stewart Island²

Pelagic phase duration:

Eggs: 5–7 days⁴

Larvae: Unknown



Photo credits: Malcolm Francis

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; * Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ² Trip (2009); ³ Trip et al. (2011a); ⁴ Ritchie (1969)

Butterfish (*Odax pullus*), also known as greenbone, occur around New Zealand, from Cape Reinga to Stewart Island, as well as offshore islands (Chathams, Antipodes, Bounties, and Snares). They are more common in southern New Zealand (Francis 1996). A second endemic species (the blue-finned butterflyfish, *Odax cyanoallix*) is found only in the far north, in particular around the Three Kings Islands, where *O. pullus* is absent (Brook 2002). Their principal habitat is kelp-forests associated with shallow rocky reefs (Paul et al. 2000, Anderson & Miller 2004). Juvenile fish have initial diets that contain substantial amounts of animal material, before switching to an exclusively herbivorous diet with increasing age, particularly the brown macro-algae *Ecklonia radiata* and *Carpophyllum* spp. (Choat & Clements 1992, Clements & Choat 1993). A related *Odax* species in Australia, the herring cale (*Odax cyanomelas*), is known to be shifting its distributional range southwards as a result of increasing global environmental temperature. Previously typically abundant only in Bass Strait, this species is now widespread on reefs along the eastern and south-eastern coastlines (Last et al. 2011).

Spawning

Butterfish have a ‘monandric protogyny’ reproductive strategy, where all fish are initially female, with males developing from mature females after a female-to-male sex change. Females in the Hauraki Gulf mature at 1.1–1.5 years of age (229–265 mm), with sex change estimated to occur around 2–3 years of age (359–379 mm) (Trip et al. 2011b). Butterfish are serial spawners over a long spawning season extending from July to March in Cook Strait, and August to January in Otago (Ritchie 1969). Significant latitudinal trends in growth, body size, development, and longevity are evident, with individuals growing slower, maturing and changing sex later, achieving larger body sizes and living longer at more southern latitudes (Trip 2009).

Egg and larval transport

There is little information on the egg and larval stages of this species. Ritchie (1969) found fertilised eggs in Wellington coast inshore plankton over an eight-month spawning period (July–February), but was unable to capture any larvae. Based on the rearing of artificially fertilised eggs in the laboratory, he reported that eggs hatched at 116 to 160 hours (5 to 7 days). Colour on hatching was generally bright green but some remained the yellow colour that appears soon after egg fertilisation. These larvae drifted, and were observed to often sink in still water, with the last larvae surviving to 2 weeks. Based on these observations, and the lack of planktonic larvae, Ritchie (1969) suggested that butterflyfish larvae “leave the plankton and begin a demersal life soon after hatching”. Robertson (1973) reported eggs from close inshore in Otago waters, from October to January, and suggested that the spawning season in the south was shorter (relative to Cook Strait) due to colder water temperatures. Larval fish assemblage sampling further north around Kaikoura Peninsula did not return any butterflyfish larvae (Hickford 2000), despite adults being common in this area (Hickford & Schiel 1995). A number of fish larvae studies in the Hauraki Gulf have also failed to capture any butterflyfish larvae

(Roper 1986, Kingsford 1988, Kingsford & Choat 1989, Tricklebank et al. 1992). Hickford (2000) suggested that potential reasons for the absence of butterfish larvae (and larvae of other common reef species, e.g. blue moki *L. ciliaris*, and banded wrasse, *Notolabrus fucicola*), might include a narrow depth distribution, or an extended offshore development (e.g. blue moki, Francis 1981b).

Juvenile habitats

Juvenile fish are found in the shallower parts of coastal rocky reef systems supporting brown kelp forests, and undergo an ontogenetic shift with age into the deeper parts of the adult range (Paul 2000). Recruitment across years may vary strongly, based on informal observations of juvenile numbers in the Leigh Marine Reserve over several years (M. Morrison, pers. obs.)

Adult habitats

Butterfish range in distribution from North Cape to the Snares Islands, as well as occurring at the Chatham, Bounty and Antipodes Islands (Francis 1996, Brook 2002). They inhabit rocky coastlines, and are most abundant in areas with moderately turbulent water with associated dense brown kelp forests, with their main food source being *Ecklonia radiata* and *Carpophyllum* spp. (Paul 2000) There appears to be a latitudinal cline in depth range, extending from the immediate subtidal zone down to around 10 m in northern New Zealand, increasing to around 20 m around Cook Strait, and to 40 m in southern New Zealand (Ritchie 1975). Abundances are higher in general from Cook Strait southwards (Choat & Ayling 1987, Paul et al. 2000, Trip 2009), although in some areas they are relatively rare. For instance, in a survey of fish assemblages along the west coast of the South Island, no butterfish were encountered in Milford Sound, which was attributed to the rarity of brown algae (Roberts et al. 2005). It was recorded further north at Jackson Bay sites (0–15 m water depths), but was not encountered in the Haast–Buller area. Occasional fish are reported to be caught in the northern part of that area (Greymouth to Westport) (D. Neale pers. comm., 2004; in Roberts et al. 2005). Roberts et al. (2005) commented that the shores and reefs along this coast are often composed of granite or sedimentary boulders and bedrock, which are barren of kelps. They attributed this to high levels of suspended sediments reducing light levels, and the associated scouring effects on the seafloor (NB: these sediments are largely derived from the naturally very high erosion rates of the Southern Alps). The bull-kelp *Durvillaea* spp. was however relatively common at exposed sites along the Haast–Buller coast. In the Leigh Marine Reserve, Hauraki Gulf, rock type was also found to have a significant effect on butterfish abundance, with fish being more common in dissected greywacke reef areas, relative to areas of flatter sandstone reefs (Meekan 1986).

Cole et al. (2012) quantified habitat use of shallower water reef-fish species across three New Zealand locations (East Cape, western Cook Strait, and Stewart Island). Butterfish at East Cape were found to be statistically associated with shallow water depth, the occurrence of bed rock, and high brown macroalgae cover, with a positive Pearson correlation for all canopy cover combined ($r = 0.21$). Similar habitat associations were seen in the Cook Strait region ($r = 0.45$ for canopy cover), and at Stewart Island (r not given). It was concluded that there were “consistent, clear, links between the abundances of herbivores of brown macroalgae, such as *Odax pullus*, and macro-algal cover” (Cole et al. 2012).

Pérez-Matus & Shima (2010) used manipulative field experiments to vary brown algae densities and species composition (using *Macrocystis pyrifera*, *Carpophyllum maschalocarpum*, and *Cystophora retroflexa*) within small discrete 4 m² plots. Plot treatments varied in terms of 1) single macroalgal species, (2) combinations of macroalgal species (i.e. mixed stands), and (3) macroalgal density. Different plot treatments were deployed within a randomly assigned array, with a distance of 1.5 m between individual plots (all in situ algae cleared from the array area). This experiment was deployed

across an outer Wellington harbour site, and a nearby semi-exposed coastal site off Island Bay. Butterfish were only observed at the coastal site, and only across treatments including the giant kelp *M. pyrifera*, and *C. retroflexa*. Only the treatment of '2x' giant kelp density had a significantly positive effect on butterfish abundance, while treatments of 'ambient' giant kelp densities, and mixed algae, were not significant. It was concluded that butterfish could be assigned to a reef fish species group defined as 'specialists', where the presence of macroalgae increased their abundance or frequency of occurrence (Pérez-Matus & Shima 2010).

As well as being affected by habitat presence, butterfish have recently been shown to be a species that can profoundly affect biogenic (macro-algal) habitat structure at potentially large spatial scales. Taylor & Schiel (2005) removed bull-kelp (*Durvillea antarctica*) canopies, and measured subsequent bull kelp recruitment. Recruitment was highly variable through time, largely driven by when canopies were removed during the year, while spatially there was an order of magnitude difference in recruitment between sites. Butterfish were a major mortality source for young bull-kelp recruits, with its grazing marks observed on recruits, and 80% of recruits outside of bull kelp canopies being grazed. They concluded that while bull kelp recruitment was initially positively related to the degree of adult canopy protection, where they largely escaped fish grazing, subsequently those recruits grew poorly, and eventually died unless the canopy was removed. Conversely, while recruits settling outside of canopies were largely eaten, those that survived had much higher growth rates. Plants older than one year were located away from adult stands. Taylor & Schiel (2010) followed on from this work. Using a series of experiments, they showed that fish grazing greatly reduced the cover and biomass of bull-kelp, with these effects decreasing across an environmental gradient of increasing wave stress and algal canopy cover, effectively limiting bull kelp to exposed conditions. In conditions of sparse algal canopies at sheltered and semi-exposed sites, almost all plants were removed by fish. Based on these findings, they calculated that for a single reef platform 30 m long, where butterfish completely removed bull-kelp recruits each year, 450 kg of potential bull-kelp biomass was lost annually (for plants less than one year old and one metre in length); given the opportunity to develop into a full adult canopy, the standing biomass of this reef platform could have been up to 2000 kg. Scaling this up along the coastline of southern New Zealand, they described the impact of this consumer (butterfish) as "*potentially enormous*" (Taylor & Schiel 2010).

Adult migrations and movements


Knowledge of movement in this species is very limited. At fine scales, butterfish are active during the day, making regular migrations across reefs to different depths, depending on tidal state (Clements 1985, Meekan 1986). Clements (1985) observed two fish (210, 300 mm FL) to traverse about 300 m over two respective periods of 25 minutes. Paul et al. (2000) concluded that on the basis of this species being restricted to rocky reef kelp forests habitats, the territorial behaviour of males, and localised spawning behaviour, that overall movement was likely to be minimal. It was however also noted that where shallow reef complexes were widely separated, local movements clearly occurred, with fishermen reporting that heavily fished reefs usually recovered within a month.

Population connectivity

The number of butterfish stocks is unknown (Paul et al. 2000). Examination of some taxonomic characters (vertebrae, scale rows, fin rays) across a range of New Zealand sites (Leigh, Wellington, Marlborough Sounds, Kaikoura, Dusky Sound, and Stewart Island), found minor geographic variations, as well as some variation within regions, with no conclusions about possible stocks (Ritchie 1969). Paul et al. (2000) concluded that butterfish populations on offshore islands (Chathams, Antipodes, Bounties, and Snares) are likely to be distinct from the mainland population(s) because of their isolation. They also suggested that because this species has such restricted habitat requirements,

with movement between discrete reef areas facing barriers such as long sandy coastlines and deep straits, there was likely to be some degree of geographical isolation (and hence population differentiation) present.

3.8 Elephant fish (*Callorhinchus milii*)

<p>Fisheries catch: Commercial: 1384 t¹ Recreational: 3500 fish^{1*}</p> <p>Sexual maturity: Males: 3 years / 50 cm², Females: 4.5 years / 70 cm²</p> <p>Maximum age: >10 years³, possibly > 20 years⁴) / 100 (FL)³</p> <p>Reproductive mode: Extended oviparity with benthic egg cases (which incubate for 25–34 weeks)⁵</p>	 <p>© NIWA M. Francis</p>
<p>¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; * Numbers of fish only. Estimates from the 1999 – 2000 survey regarded as most accurate. See Plenary document for caveats around use of these data; ²Gorman (1963); ³Francis (1997a); ⁴Coutin (1992); ⁵Lyon et al. (2011)</p>	

This species is found in both New Zealand and Australia. In New Zealand, it is most common along the east and south coasts of the South Island down to around 150–200 m depth. They are uncommon off the North Island but occasionally recorded from the eastern Bay of Plenty, south of East Cape, and on the west coast, possibly as far north as the Kaipara Harbour (McMillan et al. 2011). In Australia, the species is distributed from Esperance in Western Australia across to Sydney in New South Wales, including Tasmania, at depths to at least 200 m, but the main concentrations are in Bass Strait (Last & Stevens 1994). Elephant fish, like other species of *Callorhinchus*, are benthic foragers, primarily over soft substrate, using their club-like protrusion on the snout to search for prey, mainly molluscs such as *Maorimactra ordinaria*, along with crustaceans and some fish (Cox & Francis 1997).

Spawning

Elephant fish are oviparous with adults aggregating in shallow inshore waters (including harbours, bays and estuaries) during spring to mate and females separating to lay their keratinous eggs. In the Marlborough Sounds, breeding takes place between November and January. After spawning adults move back offshore into deeper water during the summer months and remain deep during winter.

Egg and larval transport

Not relevant.

Juvenile habitats

Gorman (1963) described eggs being laid between the surf zone and 37 m, in sand or mud substrata. Areas where egg cases are found in high numbers include the Marlborough Sounds, Pegasus Bay and Canterbury Bight. Sites where spawning or high densities of egg cases have been observed include Iwirua Point and Kumutoto Bay in Queen Charlotte Sound, from Fitzroy Bay to Savill Bay, Garnes Bay, Kumutoto Bay and Grove Arm in Pelorus Sound and Clifford Bay (Didier 1992, www.marlborough.govt.nz, C. Duffy pers. obs.). Observations were made in less than 25 m depth and the substrate in these areas is described as fine sand and broken shell. Graham (1956) also reported that Blueskin Bay was a favoured nursery ground and empty egg cases were commonly washed or trawled up.

In Australia, Western Port Bay, (southeastern Australia) is the only confirmed nursery ground, described as “*elephant triangle*”, it attracts fish “*in plague proportions*”. Braccini et al. (2008)

assessed habitat requirements for breeding aggregations of Elephant fish in this area. They found that fish occurred in highest numbers over muddy-sandy habitats located in the proximity of seagrass meadows. Areas of highest catches of females were characterized by bare intertidal and subtidal flats with high concentrations of fine sand, silt and clay, and little tidal current. Males and females were also caught in channels and deeper tidal areas. Industry accounts suggest egg-laying also occurs in equivalent habitat around Tasmania (2011 Shark Resource Assessment Group Stock Assessment).

The eggs are designed to trap sediment and anchor themselves into the mud, taking around 5–8 months before hatching. Using data collected from trawl samples collected over a 23 year period from Canterbury Bight and Pegasus Bay, Francis (1997a) observed that the smallest specimens (10–16 cm) were first seen in May with a peak hatching around May–July. Francis also noted that newly laid eggs were found as late as the beginning of June in Marlborough Sounds. Juveniles remained in the shallow habitats for up to three years with up to four length modes present in these shallow depths (Francis 1997a, Beentjes & Stevenson 2000). Differences in growth rates were inferred from length frequency data collected in Pegasus Bay compared to Canterbury Bight, suggesting that mixing of juveniles between these two areas was minimal (Francis 1997a). The higher water temperature in Pegasus Bay was suggested as the reason for faster growth in this area. Although not so well documented, newly hatched juveniles have also been found in Porirua and Pauatahanui Inlets, Wellington Harbour, the west coast of the South Island, Blueskin Bay, Otago Harbour, and Te Waewae Bay (Graham 1956, Jones & Hadfield 1985). In Australia, Braccini et al. (2008) carried out a scuba survey and found high concentrations of eggs in the outer margins of subtidal areas on sandy sediments with patches of seagrass (*Halophila australis*) and that neonates were observed in the nearby seagrass meadows.

Juvenile elephant fish have been caught on *Kaharoa* trawl surveys off the south-east coast of the North Island (in 10 tows) and east and west coasts of the South Island (in 258 tows). The largest catch rates (up to 1.1 t.km⁻²) were from the east coast South Island, often in the shallower part of the species depth range (Hurst et al. 2000a).

Adult habitats

The inshore trawl surveys along the east coast of the South Island record their highest catches between Oamaru and Banks Peninsula in 10–50 m of water (Beentjes & Stevenson 2000). Additional survey strata in 5–30 m in previous summer surveys caught elephant fish throughout the area, with highest abundances off Lake Ellesmere. Catches in these inshore strata have been more variable in the winter survey series (Beentjes & Stevenson 2001). A recent analysis of commercial catch in ELE 3 and 5 also indicated highest catches in the inshore areas of the Canterbury Bight, Pegasus Bay as well as Te Waewae Bay, west of Foveaux Strait (Starr & Kendrick 2013, see Figure 6 below).

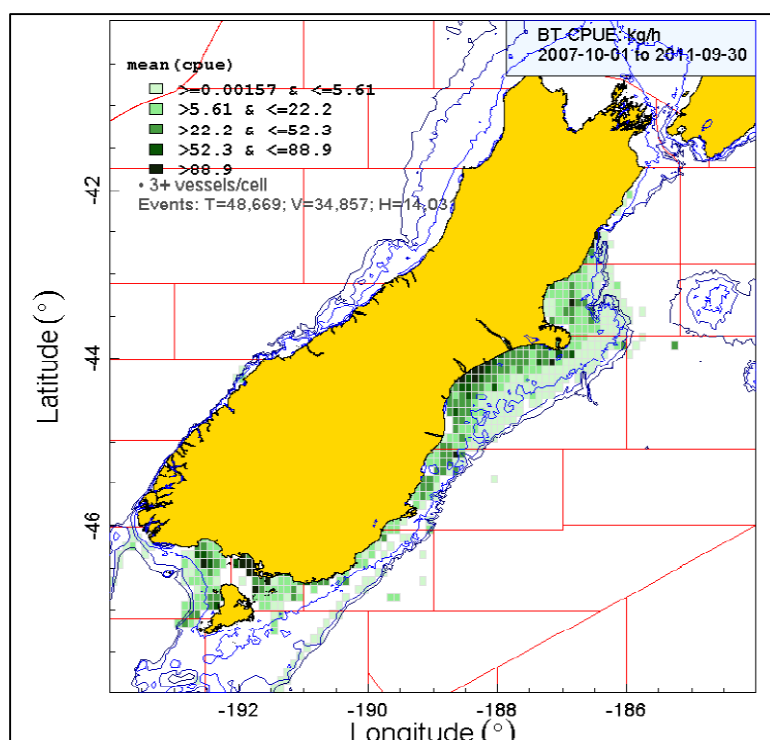


Figure 6: CPUE trawl landings of elephant fish along the east coast of the South Island (by $0.1^{\circ} \times 0.1^{\circ}$ grids). (Source Starr & Kendrick 2013).

Adult migrations and movements


Large migrations of mature female elephant fish are known to enter the Pegasus Bay area in spring each year to lay their eggs (Gorman 1963, Sullivan 1977), with the eggs being laid on sand or mud, from the surf zone to about 37 m deep (Gorman 1963, Allison & Coakley 1973). Large numbers of egg cases, mostly empty but occasionally containing embryos, wash up on Christchurch beaches after storms (Graham 1956, Gorman 1963).

Between 1968 and 1970, 548 and 1345 elephant fish were tagged and released in Pegasus Bay and the Canterbury Bight respectively. Most of the fish tagged were large juveniles. Only 5 tags were returned from Pegasus Bay, and 77 from the Canterbury Bight (Francis 1997a). The majority of tagged fish remained in the Canterbury Bight, with nearly half moving less than 20 km from the release point, and just 5 fish recaptured outside the Canterbury Bight (McClatchie & Lester 1994). Of those, 3 had moved north of Banks Peninsula, one reaching Kaikoura, and two had moved south as far as the Waitaki River and Otago Peninsula. These tagging studies confirm that juveniles generally remain within the nursery area, potentially moving further away as they mature, but does not provide any information on the seasonal movements on and offshore made by the adults into and away from the breeding areas. This movement is reflected in commercial data with vessels fishing deeper during the autumn and winter compared to the summer months (Starr & Kendrick 2013).

Population connectivity

The boundaries given to the elephant fish stocks relate to historical fishing patterns rather than biological information, but it is likely that sub-populations exist in different areas with as yet unidentified nursery areas supporting them.

3.9 Frostfish (*Lepidopus caudatus*)

<p>Fisheries catch: Commercial: 1106 t¹ Recreational: Unknown</p> <p>Sexual maturity: Males: 97 cm / Females: 111 cm, in NW Mediterranean²</p> <p>Maximum age: 165 cm (NZ)¹, 196 cm / 8 years in NW Mediterranean²</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: Unknown</p>	 <p>© NIWA D. Stotter</p>
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¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; ²Demestre et al. (1993)

Frostfish occur globally across the continental shelf and upper slopes of all oceans, excluding the Pacific. Recent genetic work has found significant differences between the northern and southern hemisphere clades, and it suggested that there is an unrecognised cryptic species within this putatively single species global distribution (Ward et al. 2008). As a benthopelagic species, they migrate into the midwater zone at night. Their diet is composed of crustaceans, small fish and squid (Nakamura & Parin 1993) and overseas studies report a dominance of crustaceans (euphausids and *Pasiphaea* spp.) in the northwest Mediterranean (Demestre et al. 1993), and myctophids (mesopelagic fish) off Tasmania, with some seasonal shifts towards euphausids and juvenile hoki (*Macruronus novaezelandiae*) (Blaber & Bulman 1987).

Spawning

Known spawning areas include the outer continental shelf, from the Bay of Islands to the south of East Cape of the North Island; no eggs have been recorded from the southeast coast of the South Island (Robertson 1980a), nor spawning on the Chatham Rise (Bagley et al. 1998b). However, spawning is known to occur on the west coast of the South Island in March (Bagley et al, unpubl. data), while small numbers of eggs have been collected in Dusky and Milford Sounds, Fiordland (Robertson 1980a). Bagley et al. (1998b) suggested that adults probably congregate in the late summer months, and subsequently spawn during the summer and winter, over the mid to outer continental shelf; Robertson (1980a) also commented that at East Cape, spawning appeared to be centred on the outer continental shelf (Figure 7). Based on egg development in that area, Robertson (1980a) calculated egg fertilisation to occur between noon and sunset, at depths greater than 50 m, in an area where the surface water temperatures were 17.5–22.0 °C.

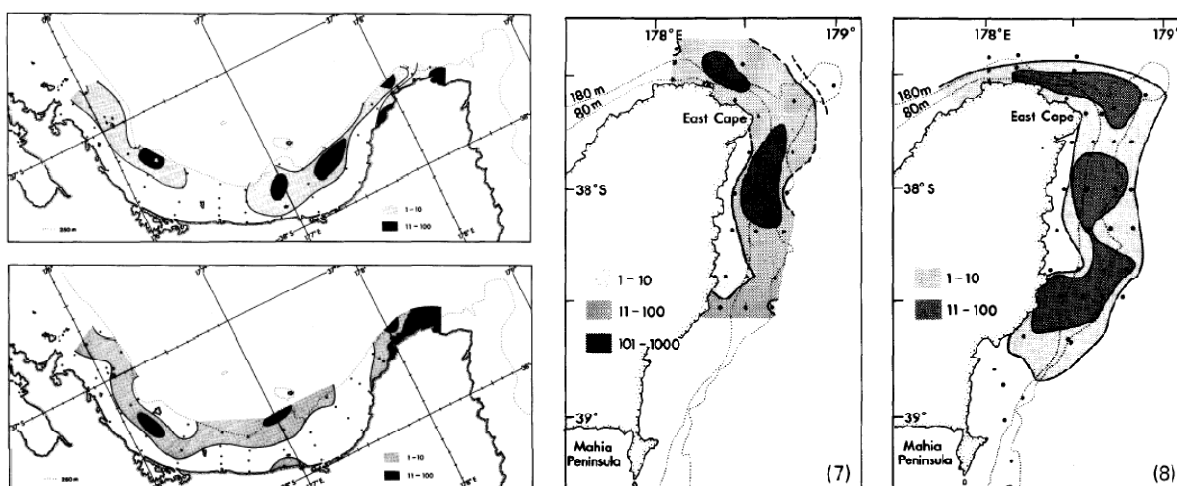


Figure 7: Left upper and lower – distribution of frostfish eggs in the Bay of Plenty region, Dec 1974–May 1975. Denotes number of frostfish eggs per 30 minute surface tow. Note: it is not clear from the original reference which specific months the above maps represent – two additional maps are also not shown here. Middle and right: distribution on frost fish eggs in the East Cape area, February 1970–April 1972. Respectively: numbers of frostfish eggs per 30 minute surface tow; lower, numbers per 500 m² of surface water (source Robertson 1980a).

Egg and larval transport

Robertson (1980a) caught few larvae, which was attributed to the possibility that they sank away from the sea surface after hatching. Keane & Neira (2008) assessed larval fish assemblages associated with water masses around south-eastern Australia, including Tasmania. Of the three distinct water masses identified (see blue mackerel sections), frostfish larvae were consistently associated with the Tasman Sea water mass (14.8–17.5° C), the most southern of the three. Gray (1993) sampled larval fish assemblages off Sydney, New South Wales, and consistently recorded larval frostfish at the 30, 70 and 100 m depth contours; within these stations, larvae were largely caught at the 20–30 m depth sampling strata, with few being captured at the surface.

Nursery habitats

Juvenile frostfish (less than 30 cm) have been sampled through research trawl surveys from off Northland, the Hauraki Gulf, the Bay of Plenty, and the west coast of both the North and South Islands. Bagley et al. (unpubl. data) reported that juveniles were trapped in trawl meshes of the W.J. Scott surveys in inshore west coast South Island waters from May to September (1981–1983), with 15 cm fish being recorded in June.

Adult habitats

Frostfish are found around New Zealand and the Chatham Island, in depths ranging from 50 to 600 m, and appear to more abundant in association with bottom temperatures of 10 to 16 °C (Bagley et al. 1998b).

Adult migrations and movements


Unknown

Population connectivity

Bagley et al. (1998b) proposed a tentative stock structure, based on spawning observations in three different areas occurring at a similar time of year, as well as juvenile and adult distributions. These areas are: a) Bay of Islands to East Cape region, known spawning area; b) Fiordland, Puysegur Bank

and Stewart/ Snares shelf, known spawning area and commercial catch at latter two areas, and c) west coast South Island, where most of the commercial catch was taken, and a known spawning area occurs.

3.10 Gemfish (*Rexea solandri*)

<p>Fisheries catch: Commercial: 860 t¹ Recreational: <1 t^{1*}</p> <p>Sexual maturity: 4–6 years / 60–70 cm²</p> <p>Maximum age: 15 years¹</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: Unknown</p>	
<p>¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; *Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ² Rowling (2003)</p>	

Gemfish are a semi-pelagic mid-water species, found predominantly at water depths of 200–600 m on the continental slope. They occur in New Zealand and Australia, with genetics work indicating a possible low level of mixing between the two regions, but not enough to view them as a single stock (Paxton & Colgan 1993). The distinction between eastern Australian and New Zealand gemfish is less clear than between eastern and south-western Australian gemfish, and gene flow is estimated to be six to seven times higher across the Tasman Sea (Colgan & Paxton 1997). Catches from the southern stock of New Zealand gemfish (see following) peaked at around 7000 t in 1988, but declined to 130 t by 1995–96 (Renwick et al. 1998). Investigations of commercial and research data over 15 years suggested a major abundance decline, with large between year variations in the numbers of small fish recruiting to the fishery. This variation appeared to be strongly linked to the frequency of occurrence of southwesterly wind flow over New Zealand, and to sea surface temperature variations during the winter spawning period (spawning success is reduced with lower temperatures and higher southwesterlies) (Renwick et al. 1998). Similarly, the east Australian gemfish stock (NSW coast) experienced a recruitment failure in the late 1980s, and has not since recovered (Rowling 1995).

Spawning

Commercial fishing around the North Island is very seasonal (Hurst & Bagley 1998, Hurst et al. 1998), which it is suggested reflects an autumn spawning migration from the central east coast up into more northern waters (Horn & Hurst 1999). Commercial catch seasonality, spatial trends, and sampled catch gonadal stages indicate that the northeastern fishery exploits a prespawning northward migration, from April to June (Langley et al. 1993), although there is some potential confounding with the vessels involved moving away to target hoki and orange roughy in June and July.

In southern New Zealand, evidence of spawning activity has been noted on the west coast of the South Island in August–September, near or above the winter thermocline (200–300 m depth) (Hurst & Bagley 1998). Most of the fish sampled from catches off the northern North Island come from late May to early July when the fish are maturing (eggs visible). There are also a few sporadic records of ripe females on the Stewart-Snares shelf and on the western Chatham Rise.

Egg and larval transport

Little information could be found on the early pelagic life history stages. Eggs are known to be positively buoyant (Renwick et al. 1998). Renwick et al. (1998) assessed the correlations between surface climatic factors (March to October, 8 month window) and subsequent gemfish year class strength (YCS), for the west coast of the South Island. Strong YCSs were associated with infrequent southwesterlies, and positive sea surface temperature (SST) anomalies. This was described as being “*physically consistent*”, with increased southwesterlies being associated with low SST through greater upwelling, heat flux out of the ocean, and the advection of cool surface water northwards. Renwick et al. (1998) concluded that a number of possible explanations might match the observed relationships, but all were speculative, given the lack of knowledge of gemfish biology, especially of the stage in the life history at which YCS was determined.

Nursery habitats

Young gemfish (15–30 cm long, 6–12 months old) are most often recorded from the west coast of the South Island and the Bay of Plenty, consistent with the distribution of ripe females (Hurst et al. 2000b). Stevenson & Hanchet (2000a) commented that while the East Coast South Island research trawl surveys (1993–96) appeared to monitor pre-recruit gemfish (albeit relatively imprecisely), the main areas of abundance were adjacent to large areas of foul ground (presumably reef). They suggested that this may have affected the proportion of the juvenile population vulnerable to trawling each year; and by implication that significant proportions may have been using these areas of foul ground.

Adult habitats

See below.

Adult migrations and movements

Strong seasonal patterns of commercial fishing occur around the North and South Islands, in terms of target locations and monthly catches (Hurst & Bagley 1998, Hurst et al. 1998), from which spawning migrations are strongly inferred.

In northern New Zealand, an inferred autumn (May) spawning migration occurs from the central east coast up into more northern waters (Horn & Hurst 1999). Mostly pre-spawning fish are caught in late May–June in the Bay of Plenty, and off east and west Northland. By August–September, a few post-spawning fish are caught in the Bay of Plenty, while fish caught further south off the Wairarapa coast from October–April have resting stage gonads, with some found in pre-spawning mode in early May. Horn & Hurst (1999) also mention the development of a new winter fishery on the western side of North Cape, but were uncertain of the possible origins of these fish – no new information appears to have become available since then.


In southern New Zealand, commercial and research survey data suggest a seasonal spawning migration from Southland up to the west coast of the South Island. Evidence for this includes the absence of fish larger than 70 cm in June, and their subsequent ‘return’ in November (1986 survey data). The highest seasonal catch rates (during the fisheries peak 1980s fishing years) suggest a spawning migration to the west coast in August–September.

Population connectivity

There are considered to be two gemfish stocks in New Zealand, based on patterns of year class strengths, commercial catch trends, and likely spawning areas: with one located off the east and north of the North Island, and another off the west and south of the South Island (Horn & Hurst 1999). The

north-eastern stock is caught mainly on the east coast of the North Island, south of East Cape, in spring through to autumn, and thought to then migrate north to the Bay of Plenty and North Cape to spawn in winter; the south-western stock is caught off the Southland coast from spring through to autumn, and thought to then migrate to the west coast of the South Island to spawn in August–September (Hurst & Bagley 1998). A fishery that had recently developed (as of 1997 – Annala & Sullivan 1997) to the west of Northland was considered to have an unknown stock affinity. Langley (1995) suggested that the North Island east and west fisheries might represent separate gemfish substocks, each migrating northwards along the coast each year (based on catch rates), while Horn & Hurst (1999) suggested a single northern stock (based on age frequencies, likely migration patterns and spawning areas, and CPUE trends).

3.11 Giant stargazer (*Kathetostoma giganteum*)

<p>Fisheries catch: Commercial: 3203 t¹ Recreational: – ~1500 fish^{1,2}</p> <p>Sexual maturity: 40–55 cm / 5–7 years³</p> <p>Maximum age: 86 cm / 25 years^{4,5}</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: Unknown</p>	 <p>© NIWA P. Shearer</p>
<p>¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ²Bradford, 1998; ³Manning, 2008; ⁴Manning & Sutton, 2007; ⁵McMillan et al. 2011</p>	

Giant stargazers are endemic to New Zealand, and are distributed from the Three Kings Islands to just south of the Auckland Islands, in water depths of 10–900 m (McMillan et al. 2011).

Spawning

There is no evidence for discreet spawning areas, with spawning thought to take place mainly in winter months on outer shelf to slope areas throughout New Zealand. Hurst et al. (2000a) combined data from trawl surveys and found that ripe, running ripe and spent fish were present year round, but never exceeded 40%. Highest numbers occurred around the Auckland Islands, (June to September and April), in Southland (August–October), on the west coast of the South Island (June to September), east Chatham Rise (April to September) and the east coast of the North Island (December and February). The on-going west coast trawl surveys find that most adult fish are maturing or mature during March/April, with very low numbers of running ripe or spent fish (Stevenson & Hanchet 2010). Few ripe or running ripe fish are found in the east coast South Island surveys (May/June), but eggs were found occasionally along the southeast coast in spring (Robertson 1975).

Egg and larval transport

Little information exists. Low numbers of larvae have been caught in light and sound traps deployed in Omaha Bay in the outer Hauraki Gulf (Tolimieri et al. 2000).

Nursery habitats

Juveniles (less than 30 cm) are most commonly caught off the east and west coasts of the South Island and in Tasman Bay in research trawl surveys. Recent surveys on the west coast of the South Island have recorded an increase in the proportion of juveniles (modes at 20–25, and 25–30 cm) from less than 6% in earlier surveys to 14% and 13% in 2007 and 2009 respectively (Stevenson & Hanchet 2010). On the east coast, large catches of juveniles have been recorded in the Canterbury Bight (up to 0.3 t km⁻²) with the smaller average fish size in this area compared to others leading to the suggestion

that this may be a particularly important nursery ground (Beentjes et al. 2010a). Catches of juveniles around the northern and south-east coast of the North Island were far lower (Hurst et al. 2000a). On the Chatham Rise catches of juveniles are patchy, mainly concentrated on the western Rise between 200–300 m. The abundance of fish in Chatham Rise waters shallower than 200 m is unknown, since surveys do not generally fish shallower than 200 m.

Adult habitats

Giant stargazers are most common around the southern South Island (e.g. Puysegur–Solander Corridor), and at Mernoo Bank. High catches are also recorded in Cook Strait, along the east coast of the South Island, and off Westland. The species is recorded in both the east and west coast South Island trawl surveys; with the highest west coast catches being taken south of Cape Foulwind, between 100 to 200 m. This species occurs mainly on sandy or muddy sediment, where it uses its pectoral fins to bury itself to ambush passing prey (McMillan et al. 2011).


Adult migrations and movements

As part of validating ageing studies, during an East Coast South Island trawl survey fish were injected with oxytetracycline, externally tagged, and released. A subsequent lack of tagged fish returns (1 only, without otoliths) resulted in this tagging programme ending.

Population connectivity

Growth appears to differ between the east, south and west coasts of the South Island (Manning & Sutton 2004, Manning 2005) suggesting different biological stocks within these areas. However, beyond this, little is known about how stocks are structured, and what scale of movement individual fish might undertake. A similar benthic, solitary fish, the Atlantic monkfish (*Lophius americanus* and *Lophius piscatorius*) has been shown (using data storage tags) to undertake vertical migrations to varying degrees, interpreted as a tidal transport mechanism (Hislop et al. 2000, Laurensen et al. 2005, Rountree et al. 2008, Landa et al. 2008).

3.12 Grey mullet (*Mugil cephalus*)

<p>Fisheries catch: Commercial: 826 t¹ Recreational: 100–150 t¹ for GMU 1[*]</p> <p>Sexual maturity: 3 years / 33–35 cm¹</p> <p>Maximum age: 14 years / 60 cm¹</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: Unknown</p>	
<p>¹ For year ending 30/09/2011. MPI Assessment Plenary Document, Part 1, 2012; *Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates.</p>	

Grey mullet are a globally distributed species, found through temperate and sub-tropical areas of both hemispheres. They are capable of large scale movements; in an Australian tagging study an adult fish tagged in an estuary moved some 350 miles to the north over a 485 day period, being recaptured off a coastal beach (Thomson 1955). Livi et al. (2011) assessed grey mullet genetics globally from 14 regions across the northern and southern hemispheres, including east and west Australia. They reported a deep genetic divergence between the different regions, indicating a very low connectivity between the different populations. The east and west Australia populations were quite distinct from

each other; of interest the east Australian population was identified overall as being most likely to be the centre of origin for *M. cephalus* as a species.

In New Zealand they are generally restricted to more northern temperate waters, with the main fisheries being in the upper half of the North Island, although grey mullet have been reported from Porirua Harbour (no sizes provided; Jones & Hadfield 1985, Strickland & Quarterman 2001), and Makara Stream, Wellington (Jellyman 1977).

Spawning

Limited information is available on grey mullet reproduction in New Zealand. Hore (1988) recorded seasonal peaks in the female gonadosomatic index occurring in December–January, while juveniles 20–35 mm in size have been sampled by beach seine in the Manukau Harbour in February, suggesting a January spawning period. McDowall (1988) suggested that most grey mullet are thought to migrate to seawater environments to spawn. Chubb et al. (1981) also concluded that circumstantial evidence suggested spawning at sea in Western Australia, with no running-ripe grey mullet being sampled in the Swan-Avon estuary. They suggested that spawning ran from May through to November, a period of seven months. Rivers sampled to the north of the Swan-Avon only held 0+ grey mullet if they were permanently open to the sea, or where the sand bar blocking the entrance had been breached by heavy winter rainfall and associated river flows, indicating that larval supply from the sea was needed (Lenanton, unpubl. data, cited in Chubb et al. 1981). In one system (Greenough Inlet) which was temporarily closed in 1977, all fish caught the following summer were more than 1 year in age (i.e. there was no recruitment), despite the presence of adult fish in the estuary during the closed period, indicating that these fish did not spawn in that year. Similarly, ripe grey mullet trapped in the St Lucia estuary in South Africa by the closure of the estuary mouth did not spawn, and eventually resorbed their gonads (Wallace 1975).

In New Zealand, it is thought that grey mullet spawn at sea, with running-ripe females having been caught only off coastal beaches or in offshore waters. While this is probably true, in line with overseas studies, there is no actual published data to be found that supports this. Hutton (1872) reported that grey mullet in the Waikato River migrated to sea in November to spawn, returning in March. Hector (1897) supported these observations, but further added that there were actually two spawning seasons, summer and winter, and that “*this difference probably represents two distinct species of mullet*” (these two reports have not been sighted by the authors of this report, the above is as described by Paulin & Paul 2006). Paulin & Paul (2006) examined the historical grey mullet fishery of the Kaipara Harbour in quite some detail, and suggested that there may actually be two grey mullet species in New Zealand, the most likely second species being the sand mullet *Myxus elongates*, which is found in Australia. Hector (1887) further commented that “*The evidence ... clearly indicates that there are at least two different and distinct varieties of mullet, but whether these are distinct species, or seasonal, sexual, or only younger and older individuals has not yet been made clear. First we have a mullet that feeds in the ocean, and congregates along the coast in enormous schools. These used to be captured in large quantities by the Maoris with seine nets, which were dragged on the sandy beach. They are late in their sexual development, female fish in roe being caught up to April and May, corresponding in this respect with the grey mullet of the Australian coast ... These fish sometimes enter Kaipara Harbour in large schools, following the clean salt-water of the floodtide up the deepest channels and returning again with the ebb ... This variety of mullet is known to the fishermen and settlers as the ‘clean-gut’, ‘clean-run’ or ‘seamullet’. They are always of large size, and whenever caught, at whatever season of the year, they are in prime condition*”. Hector described the ‘clean-gut’ mullet as a “*large bluebacked kind that are rarely seen inside the harbour*”.

The second variety Hector referred to was known as the ‘settler’ or ‘muddy fish’. “*The other variety [‘muddy fish’] ... when opened they are not clean and bright, with the stomachs and intestines apparently empty, as in the case of sea-fish, but are full of slimy mud, the strong muscular pharyngeal stomach being distended with a mass of tough brown clay ... the muddy fish are caught inside the harbour only ... [and] are full of roe about the beginning of the year* (Hector 1897).

Recent interview of Kaipara fishers as part of a study of “Local Ecological Knowledge” of the harbour has also returned reports of two different recognised kinds of grey mullet, which are distinguishable from each other by appearance and behaviour. One is resident through the year in the harbour, while the other seasonally migrates into the harbour, first migrating down adjacent Dargaville Beach and associated surf beaches from the north (anonymous, ENV200907). In Western Australia and elsewhere, pre-spawning grey mullet have been observed making upcurrent coastal migrations (Kesteven 1942, 1953, 1962; Thomson 1955, 1963, Broadhead & Mefford 1956; Lenanton, unpubl. data), with Chubb et al. (1981) suggesting that the grey mullet population in the Swan-Avon Estuary was probably derived from populations spawning to the north of this river system. The coastal current patterns of the upper west coast North Island are too poorly known to infer possible oceanographic transport dynamics.

Egg and larval transport

Grey mullet larvae less than 14 days old do not actively swim (Tung 1967, Liao 1975), and are thought to passively disperse to estuarine nursery grounds in the context of Taiwan studies (Chang et al. 2000, Hsu & Tzeng 2009). Under laboratory conditions, grey mullet larvae grow to 10 mm in length after 28–34 days and to 18 mm after 42 days (Thomson 1963, Kuo et al. 1973).

Newly hatched larvae of grey mullet range from 2.2–3.5 mm (Nash & Shehadeh 1980), and start appearing as small schools in estuaries at 18–24 mm, at 30–45 days of age. Chang et al. (2000) used daily growth rings to assess juvenile grey mullet in the Tanshui Estuary, Taiwan, and reported that juveniles entered the estuary from November to March, at sizes of 17–39 mm, and associated ages of 29–67 days post-hatch. These sizes were similar to those found in other studies in the general region (Tung 1981, Lee 1992, Tzeng 1995). Juvenile length frequencies indicated that multiple cohorts were present, suggesting multiple spawning events.

There appears to be little information on grey mullet egg and larval dynamics in general. However, studies from the South Atlantic Bight of the USA have collected the smallest larval grey mullet (6 mm FL) near the edge of the continental shelf, which is therefore presumed to be the primary spawning location there (Anderson 1958, Powles 1981, Collins & Stender 1989). The only reliable documentation of *M. cephalus* spawning in the USA came from Arnold (1958), who verified spawning 65–80 km offshore in the Gulf of Mexico by watching the spawning behaviour of adult striped mullet and collecting fertilized eggs and various sizes of larvae (Bacheler et al. 2005).

Nursery habitats

Juvenile grey mullet occur in almost all of northern New Zealand’s estuaries, and have been sampled from Herekino to Kawhia Harbour on the west coast, and from Parengarenga to Ohope Harbour on the east coast, with juveniles also collected from the Wairoa River estuary, south of Gisborne (Morrison et al. 2002, Morrissey et al. 2007, Morrison, unpubl. data). They are also present within estuaries on coastal islands such as Kawau, Great Barrier, and Waiheke, though in these cases numbers appear to be much lower than those in mainland estuaries. While juveniles occur across both muddy and sandy sea-floors and from high clarity through to very turbid waters, the highest densities and overall abundances are found in the upper reaches of large estuarine systems with muddy turbid

environments (e.g. Morrison et al. 2002). Juvenile grey mullet do migrate tidally into mangrove forests, and can be found in very high numbers in these habitats (Morrisey et al. 2007, 2010), but it is not clear whether they are obligate on them to any degree. Juveniles are also found in high abundances in estuaries that do not contain mangroves, in particular Kawhia Harbour; in the Kaipara Harbour, juvenile grey mullet are also associated with intertidal seagrass meadows in lower densities than mangroves (M. Morrison, unpubl. data).

Chubb et al. (1981) assessed grey mullet populations in the Swan-Avon river system (Australia), with juveniles first being seen as early as May in the lower part of the river system, at 20–30 mm in size. Size frequency distributions of 0+ fish had two or more modes, suggesting multiple spawning events. These fish utilised the shallow estuarine banks through the year, with a general rapid movement upstream after entering the estuary, and were “*rarely observed..(in)..marine coastal waters*”, suggesting that they were estuarine-dependent. Juvenile grey mullet are detritovores (Blaber 1976, Lowe 2013), and this has been suggested as one reason they are especially associated with muddy seafloor habitats. However, Blaber (1976) found no difference in grey mullet diet between upstream and downstream sites in the St Lucia lake system, South Africa, with the author suggesting that a movement upstream may have evolved as an adaption to avoid larger predators found in the lower reaches of estuaries (Blaber 1977). Another possibility may be a preference for lower salinities (Thomson 1955). Grey mullet juveniles of 40–100 mm length have not been found in near-shore southwestern Australian waters between January and May, nor near sea beaches in south-eastern Queensland (Lenanton, unpubl. data cited in Chubb et al. 1981; Thomson 1955). In an extensive sampling programme on Cockburn Sound, a marine embayment about 19 km south of the Swan-Avon entrance, all of the grey mullet collected (n=79) were larger than 100 mm, suggesting that grey mullet did not use truly coastal habitats as nurseries (Dybdahl 1979). Based on these studies, Chubb et al. (1981) suggested that grey mullet are a truly estuarine-dependent species.

Small fish are thought to be relatively weak swimmers. Using field observations and some limited tank flume work using animals collected from the Waikato River (Huntly), Mitchell (1989) found that fish were able to pass over obstacles less than 5 m in length at water velocities below 0.15 m s^{-1} , but longer obstacles without resting areas of static water, might require velocities as low as 0.05 m s^{-1} to be overcome. It appears that only two grey mullet were caught for the flume tank study, of 85 and 96 mm in length (using 2 mm mesh traps). Rulifson (1997) found that steady swimming times of 0+ grey mullet (40–50 mm) dropped quickly in water velocities about five body lengths per second (0.23 m s^{-1}). The average burst swimming speed in seawater (only sustained for 30 seconds) was equivalent to 0.57 m s^{-1} for a 45 mm fish. Chisnall & Bellingham (1998) also described grey mullet as ‘poor climbers’ in the context of fish movements up freshwater systems. It is not clear at what age grey mullet migrate into freshwater systems, but it seems that very young fish are only found in estuarine habitats, and they become more tolerant of fresh water as they grow in size. Extensive searches of the lower 5 km of the Waikato River system for 0+ juveniles returned less than a dozen, from an area affected by tides, suggesting that fish are derived from estuaries outside of the Waikato River entrance. Larger numbers of adult fish were evident during this sampling. Current ongoing work on grey mullet otolith chemistry from a range of environments is likely to provide better life history information around time of entry into fully freshwater systems.

Blaber & Whitfield (1977) described an ontogenetic change in the feeding ecology of 0+ juvenile *M. cephalus* (and 10 other Mugilidae species) in south-east African estuaries. Fish progressed from zooplankton to zooplankton in the benthos (10–15 mm fish), from zooplankton in the benthos to meiobenthos (10–20 mm), and then meiobenthos to sand particles and associated microbenthos (15–25 mm). They argued that this dietary progression was probably only possible in the “*shallow, quiet*

waters of estuaries”, and was probably not possible on the exposed open coastline, concluding that “*estuaries thus play a vital role in providing suitable conditions for juvenile mullet to change their feeding habits to that of the adults*” (in the context of the high energy, exposed south-east African coastline).

Adult habitats

Grey mullet are found across a wide range of environments in both hemispheres, from temperate to sub-tropical waters. In New Zealand, they are largely restricted to the upper half of the North Island, although their range extends at least as far south as Cook Strait. They utilise a wide range of coastal marine environments, ranging from estuaries, through sheltered coastal areas, to open coast, including exposed surf beaches, where they were historically targeted with hoop nets by Maori (see figure 1 of Paulin & Paul 2006). Schools have been observed in very shallow waters over coastal rocky reef systems in the outer western Hauraki Gulf (M. Morrison, pers. obs.) and are targeted by some commercial fishers in the inner Hauraki Gulf over very shallow kelp beds on rocky reefs (C. Walsh, pers. comm.).

Grey mullet also range up into rivers and lakes, especially in the Waikato River catchment, being seen as far up the river system as Cambridge, with dams above this probably restricting further movement. A range of studies in the Waikato River and associated freshwater lakes using multi-panel gill nets (range of mesh sizes, 25–115 mm) have caught good numbers of grey mullet (e.g. Lake Waihi, 345 fish, 300–500 mm, one at 220 from Waikato River, Wells 1984; Lake Whangape, 184 fish, 185–450 mm, West et al. 2000, Chisnall et al. 2007; both lakes, 184 fish, 220–445 mm, Hayes 1989, Hayes et al. 1992). Grey mullet also used to be a significant customary food source in Lake Taharoa, just south of Kawhia Harbour, with juvenile fish migrating up to the short Taharoa Stream directly from the sea. McDowall (1993) noted that perhaps 15 of the approximately 70 species of mullet in the world are diadromous, although this figure was speculative given that the life history of many was poorly known; and that the distinction between (obligate) diadromous mullets and facultative wanderers was not explicit. Grey mullet in New Zealand appear to exploit a wide range of behaviours around habitat use.

Hicks et al. (2010) used electro-fishing adjacent to the Huntly Power Station, Waikato River, and found grey mullet to be the second most abundant fish sampled in waters 0.3–2 m deep, with an average density of 0.82 per 100 m². Fish were most abundant next to the Waihi Stream outlet. Grey mullet have also been reported from freshwater drains and drainage canals (Hudson & Harding 2004).

Adult migrations and movements

Grey mullet movements are poorly understood in New Zealand. A single limited tagging study was undertaken in 1987, to study movements between the Manukau Harbour and the lower Waikato River (Hore 1988, see Figure 8 below). Two hundred and fifty seven fish were tagged, 132 in the Waikato and 125 in the Manukau Harbour. As of March 1988, four months after tagging, 34 fish (13.2%) had been recovered. Fish moved between the lower Waikato River system and the Manukau Harbour in both directions, as well as being recovered along adjacent coastal beaches (commercial and amateur beach seine). The greatest distance moved was by a fish tagged in the Manukau Harbour and recaptured at Dargaville Beach. It was noted that the grey mullet fishery in the tagging areas was seasonal, although tag return processing were only maintained for the first four months after release (Hore 1988).

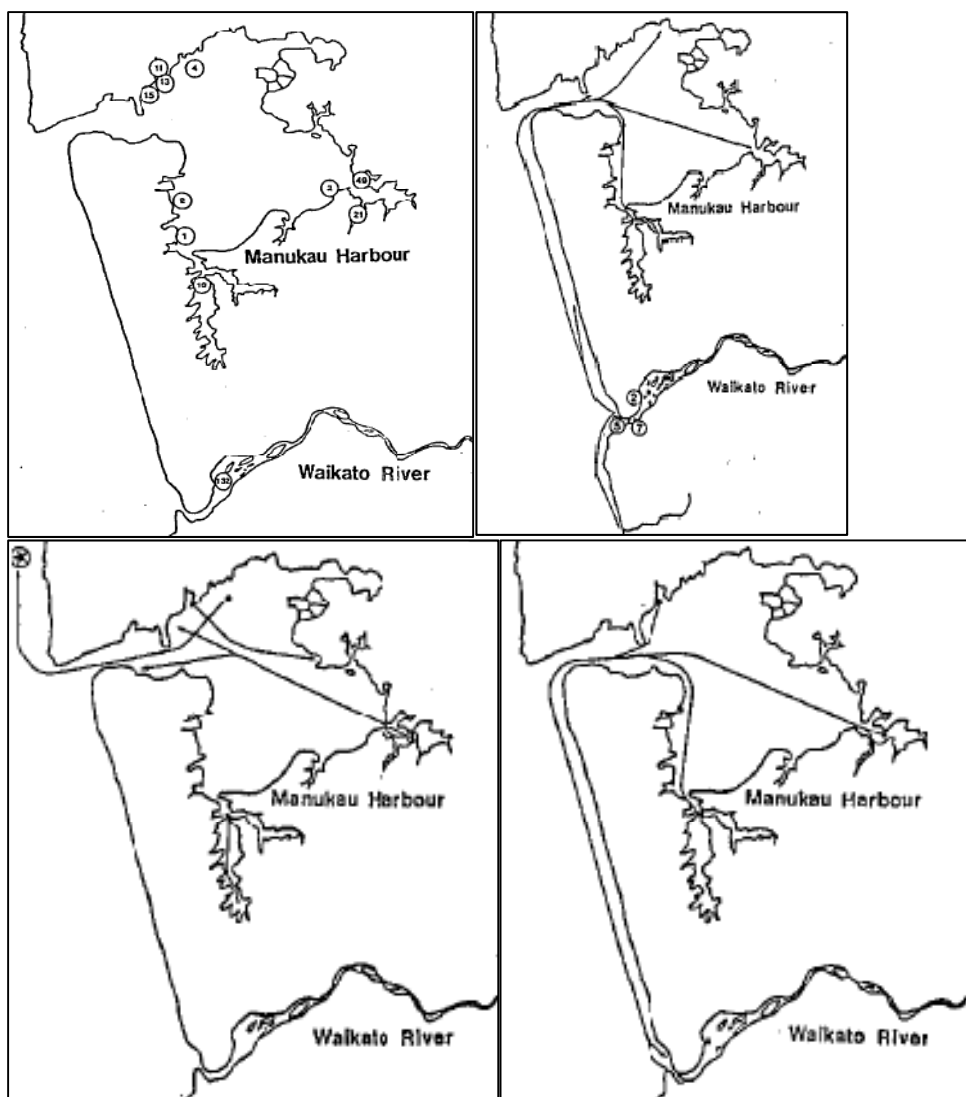


Figure 8: Top left, Manukau Harbour release sites and number of tagged fish at each; top right, Waikato River release sites and numbers of tagged fish, and shortest movement paths of recaptured fish; lower left, Manukau tagged fish recaptured in Manukau; lower right, Manukau tagged fish recaptured in Waikato River area (Source: figures 7 and 8 of Hore 1988).

Overseas tagging studies have shown that while grey mullet are capable of moving large distances, most fish remain within 100 km of where they were released. For instance, in North Carolina, while the maximum distance travelled was 860 km, the mean distance moved by recovered tag fish was only 28 km (Bacheler et al. 2005), and it was suggested that grey mullet were resident within the state's waters, with a spawning migration southwards against the north-flowing Gulf Stream currents, followed by a return movement two months later after spawning. Similarly, tagging work in Florida revealed that 90% of tag recoveries moved less than 30 km (Idyll & Sutton 1952), while grey mullet tagging in the Everglades (Florida) showed a north/northwest movement during the spawning season against the prevailing 'Loop' current, followed by a subsequent southwest return movement (Funicelli et al. 1989). In eastern Australia, Virgona et al. (1998) found 4 out of 64 (6%) tagged fish returns to have moved more than 300 km, while fish tagged by Kestevan (1953) had 70% of recaptures in the locality where they were tagged, with 8% of fish moving over 100 km.

There has been considerable recent work done on grey mullet movements and migrations overseas using otolith chemistry. In Taiwanese waters grey mullet migrate with seasonal changes in water


currents (Chang et al. 2004a). Fish of 3–4 years of age migrate southwards with the north-eastern monsoon driven coastal current from coastal mainland China waters to the waters of southwestern Taiwan, to spawn during the winter (Tung 1981, Chen & Su 1986, Huang & Su 1989). Eggs and larvae are passively transported by the coastal current to estuaries on the western coast of Taiwan, where they become juveniles at the age of 1–2 months post-hatch (Tung 1981, Lee & Kuo 1990, Chang et al. 2000). Chang et al. (2004a, b) used otolith chemistry to infer movements of grey mullet collected in Taiwan. Using Sr:Ca (Strontium/Calcium) ratios across the lifetime growth of otoliths as a marker of the salinity of waters occupied over time by individual fish, they found that after the juvenile stage, there were two groups of migratory environmental histories. The first group had Sr:Ca ratios ranging from $4\text{--}13.9 \times 10^{-3}$, indicating that they migrated between estuary and offshore waters but rarely entered freshwater habitats. The second group had Sr:Ca ratios that decreased to a minimum value of 0.4×10^{-3} , indicating that these mullet migrated to a freshwater habitat. Most fish collected nearshore and offshore fell into group 1, while fish collected from estuaries were a mixture of the two groups. Within each group there was also individual variation over time. Growth rates were similar for the two groups. Chang et al. (2004a) concluded that grey mullet migratory patterns were more plastic and complicated than previously thought.

Further otolith chemistry work by Wang et al. (2010) on freshwater dwelling grey mullet in the Tanshui River, northern Taiwan, also identified two different groups, from fish of average size 330 ± 33 mm ($n = 31$, sexually immature 1+ – 2+ fish). Sr/Ca and Ba (Barium)/Ca ratios in the otolith core indicated a freshwater dwelling group (18% of fish, higher Sr and lower Ba ratios), and a second group that had lived in marine waters in early life (82% of fish, opposite ratios). After the core otolith area, the Sr/Ca and Ba/Ca ratios alternately varied, indicating that the mullet migrated between brackish and freshwater habitats after the juvenile stage. It was not clear if the Tanshui River population was a relatively discrete local population, or how it related to the offshore migratory population (as described by Chang et al. 2004a, b). However, the authors postulated that three to four different populations of grey mullet might co-exist in the waters of Taiwan and East Asia, each with different life history traits, and collectively including both resident and migratory behaviours.

Population connectivity

There are no studies from New Zealand of how grey mullet populations are structured, and currently the species is managed as a single stock (GMU 1). Assessment of CPUE from seven different sub-stock areas found different trends from different areas, with little correlation, and this was taken as evidence of different populations being present. Research is currently in progress to assess the potential of otolith chemistry in distinguishing spatial population structuring at a finer scale, with juveniles of the 2010 year class having been collected from some 88 estuarine locations on both the east and west coasts of the upper North Island. Work on adults is scheduled for the 2014–15 year, and will include sampling of fish from a range of habitats and regions to assess natal estuarine sources, and lifetime migratory histories. It is suspected that there is considerable fine scale spatial structuring in New Zealand grey mullet populations and that migratory dynamics are diverse within populations.

3.13 Hake (*Merluccius australis*)

<p>Fisheries catch: Commercial: 5837 t¹ Recreational: negligible¹</p> <p>Sexual maturity: 6–10 years / 67–75 cm (males), 75–85 cm (females)²</p> <p>Maximum age: 25 years / 140 cm¹</p> <p>Pelagic phase duration Eggs: Unknown Larvae: Unknown</p>	 <p>© NIWA P. McMillan</p>
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¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; ²Colman (1998), Horn & Francis (2010)

Austral hake are widespread across the southern Hemisphere, occurring around the Atlantic Argentinean Shelf south of 49° S, around Cape Horn to the Chilean coast in the eastern Pacific south of 40° S, and across South Pacific waters to New Zealand (Machado-Schiaffino et al. 2009). The New Zealand populations have been shown to be both genetically and morphometrically distinct from those of South American populations (Inada 1981, Machado-Schiaffino et al. 2009).

Spawning

Three known spawning areas exist: the west coast of the South Island, west of the Chatham Islands, and on the Campbell Plateau, based on data collected by observers on commercial trawlers and trawl surveys (Colman 1998, Dunn 1998, Horn 2011). The best defined area is off the west coast South Island, with a spawning season that can extend from June to October, possibly peaking in September. The main activity centres on a small patch just north of the Hokitika Canyon in 600–700 m water depth (Hurst et al. 2000a). Spawning also takes place west of the Chatham Islands, over a period of at least September to January. Mernoo Bank (Chatham Rise) has also been recorded to have spawning fish, while spawning on the Campbell Plateau (primarily northeast of the Auckland Islands) may occur from September to February, with a September–October peak (Horn 2011). Occasionally spawning fish have also been recorded on Puysegur Bank, with a similar seasonality to that of the Campbell Plateau (Colman 1998).

There are twelve accepted species of hake (genus *Merluccius*), with Bustos et al. (2007) describing several reproductive strategies used by this genus, depending on the topography and circulation patterns of the areas in which they occur. In upwelling areas, hakes (i.e., *M. capensis*, *M. gayi*, *M. senegalensis*) spawn mainly in subsurface waters (50–100 m deep) in the vicinity of the continental shelf break during late winter and early spring, with a subsequent onshore transport of larvae (Oliver et al. 1988, 2003, Vargas et al. 1998, Sundby et al. 2001, Vargas & Castro 2001). Some species also have a movement of spawning fish to nearshore waters during the spawning season (Alvarez et al. 2004, Landaeta & Castro 2006). The Pacific hake *M. productus* spawns on the continental slope off California during January–February, coincident with lower intensities of wind-induced upwelling (Bailey 1981). Other populations of Pacific hake, found in the fiord-like environment of Georgia Basin (British Columbia) spawn in locations proximate to major sources of freshwater inflow (Gustafson et al. 2000). A sort of spawning homing (returning to the natal sites for spawning) has been deduced for the European hake *M. merluccius* based on isolation-by-distance population models (Castillo et al. 2005).

Egg and larval transport

Little information exists on New Zealand hake's life history during the egg and larval phases. Egg development of *M. australis* lasts seven days at 11.5 °C in the laboratory, and stage 1 eggs are less than four days old (Bustos & Landaeta 2005). The Chilean fiords (which are much larger than those found in New Zealand) have been identified as hake spawning zones, with large patches of undeveloped eggs present (less than 4 days old, at more than 150 eggs per 10 m²), as well as abundant larvae (up to 385 per 10 m²). Eggs and preflexion larvae (less than 9 mm) were relatively rare in open ocean-influenced waters (Bustos et al. 2007). It was concluded that these spatial patterns were possibly driven by spawning events of inland resident stocks, and/or by inshore migration of adult hake during the spring. Further out on the Chilean shelf, adults concentrate in large schools over the shelf break between Guafo and Guamblin Islands (43°30'–45°S), and eggs and larvae have been collected in abundances of less than 100 per 10 m².

Nursery habitats

Juvenile hake are found in all three New Zealand stock areas; there are differences in size frequency of hake between the west coast and other areas, and differences in growth parameters between all three areas (Horn 1997). Juveniles (0+) are often found in less than 250 m water depth (Hurst et al. 2000a).

Adult habitats

Hake are widely distributed south of 40°S, in water depths of 250 to 800 m (Colman 1998), but have also been caught along the south-east coast of the North Island and in the few deep tows around the northern North Island (Anderson et al. 1998).

Adult migrations and movements

In the New Zealand context, little information exists on movement. For hake species generally, direct studies of migration have proven to be difficult due to the high mortality of tagged fish (Jones 1974). Most hake species appear to make seasonal migrations, moving inshore and to lower latitudes to spawn in summer, and then back offshore and to higher latitudes to their feeding grounds in winter (Pitcher & Alheit 1995, Arkhipkin et al. 2003). Arkhipkin et al. (2003) used hake fishing fleet data to assess movement in *M. australis* and companion species *M. hubbisi* stocks around the Falklands and South America (see Figure 9 below). Post-spawning *M. australis* first arrive in the southwest of the FICZ (Falkland Islands Conservation Zone) in the deeper waters (400–500 m) around 53°S. Over the summer the majority of fish are in resting condition, and distributed in 200–500 m water depth over the deeper shelf in the southwestern FICZ, along with some dispersion to shallower shelf areas (less than 200 m) in the northwest, and along the 200 m contour in the north and northwest. In May, fish are concentrated on the western edge of the FICZ around 52°S, and it is assumed that they then move out of Falkland waters to spawn further to the south-west. Currently, southern American *M. australis* spawning grounds are only known off the Pacific Coast of Chile, with the main ground located between 43° and 47° S, with secondary areas between 52° and 54° S (Aguayo-Hernandez 1995). Spawning from July to September coincides with the (apparent) absence of *M. australis* from Falkland waters (Arkhipkin et al. 2003). Morphometric and parasitological data from fish from two regions (Falklands and southern Chile) suggest that both regions belong to a single inter-breeding population with several stock units (George-Nascimento & Arancibia 1994).

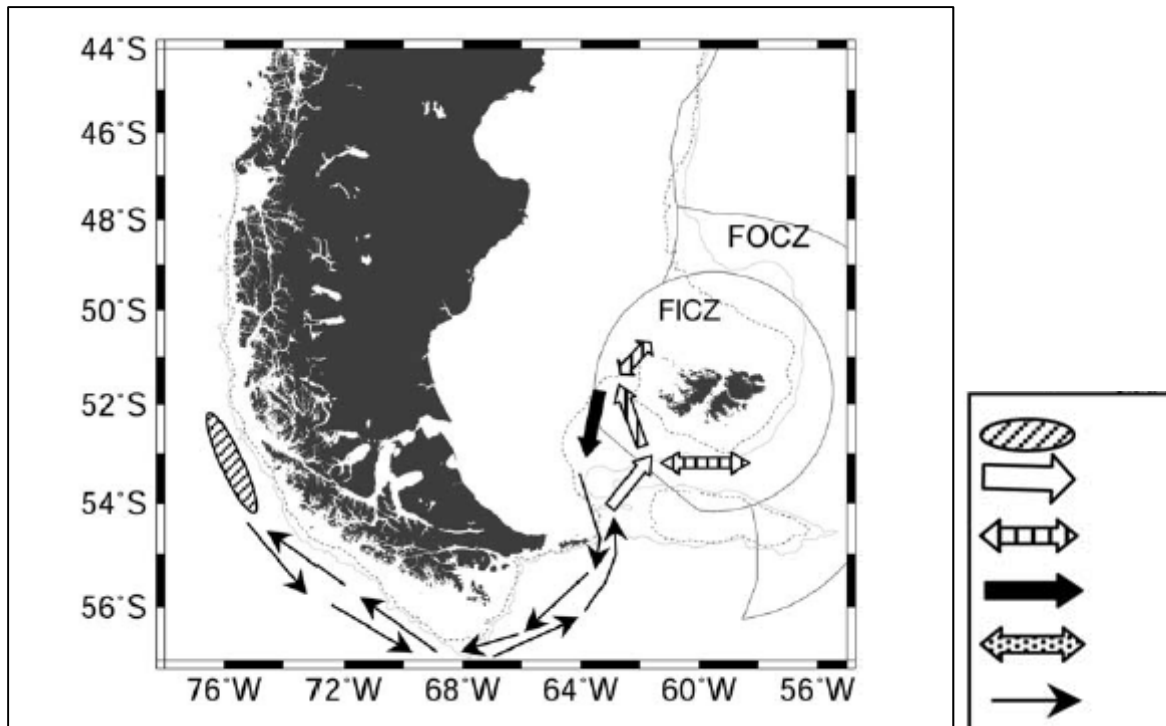


Figure 9: Scheme of possible seasonal migrations by *M. australis* in Falkland waters. Supposed spawning grounds of *M. australis* (after Aguayo-Hernandez 1995) (1); spring (2); summer (3); autumn (4) and winter (5) migrations on the feeding grounds; supposed migrations to and from the spawning grounds (6). (After Arkhipkin et al. 2003, reproduced with permission. NB: numbers correspond to the right hand key, going down the page).

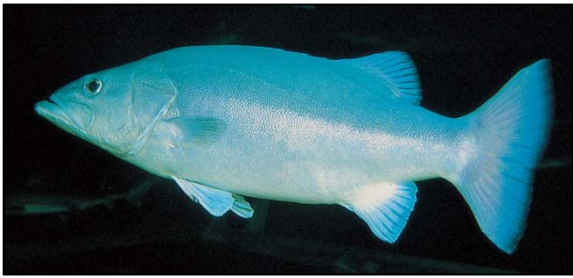
Population connectivity

Three stocks are recognised in New Zealand waters: the Challenger Plateau and west coast of the South Island (HAK 7), the eastern Chatham Rise (HAK 4), and the rest of the EEZ (HAK 1), which includes waters around the North Island, east coast South Island and the Sub-Antarctic (Ballara 2012). Hake from these three areas show differences in growth, size frequencies, and morphometrics (Horn 1997, 1998). The Puysegur Bank area (bottom southwest South Island) may be an area of stock mixing, between the West Coast South Island and the Sub-Antarctic (Colman 1997, Horn 1998, Ballara 2012).

In Canadian waters, the Pacific hake (*Merluccius productus*) forms two distinct stocks: one inshore resident stock in the Strait of Georgia; and one offshore and migratory (King et al. 2012). Discriminatory features include: 1) otolith morphology, with resident fish otoliths being more concave and less elongate than those of migratory fish (McFarlane & Beamish 1985); 2) the parasite *Kudoa paniformis* is present only in the offshore stock (Kabata & Whitaker 1981); and 3) the resident stock is smaller in size-at-age than the offshore stock (Beamish & McFarlane 1985, McFarlane & Beamish 1985, King & McFarlane 2006). From 2006 to 2008, the migratory behaviour of the offshore stock changed, shifting the whole associated fishery from the typical grounds off the west coast of Vancouver Island, to the more northerly region of Queen Charlotte Sound. This raised management concerns with respect to the unknown exploitation of any resident stocks, with a resulting study of Pacific hake stock structure in Canadian waters. Genetic techniques confirmed the existence of the offshore migratory and inshore resident populations, as well as two other genetically differentiated resident groups in deepwater inlets adjacent to Queen Charlotte Sound, backed up by differences in biological parameters and parasite infection levels (King et al. 2012). The distinctiveness of these

groups of inshore fish was concluded to be consistent with hake (*Merluccius*) species showing population genetic structure along complex coastlines, but not along linear ones (references in Iwamoto et al. 2004, cited in King et al. 2012).

3.14 Hapuku (*Polyprion oxygeneios*)

<p>Fisheries catch: Commercial: 1543 t¹ Recreational: 100–700 t^{1*}</p> <p>Sexual maturity: 10–13 years / 80–85 cm²</p> <p>Maximum age: 60 years / 178 cm²</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: Unknown</p>	 <p>Photo credit: M. Francis</p>
<p>¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; [*]Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²Francis et al (1999).</p>	

Hapuku occur off southern Australia and around New Zealand, as well as having been recorded from islands in the southern Indian Ocean, and off the Pacific coast of South America (Paul 2000). Bass, another species of *Polyprion* (known as ‘wreckfish’ elsewhere) tend to occur in deeper waters than hapuku – though the two species are collectively grouped together as ‘groper’ in fisheries reporting and management. Bass are not reported on further here, aside from as a possible indicator of hapuku dynamics. Hapuku and bass occur around New Zealand and the Chatham Islands, mainly on foul ground in 100–400 m of water (Paul 2005a).

Spawning

Hapuku spawning occurs in winter, but running ripe fish are seldom caught and spawning grounds are unknown (MPI 2012). Hapuku in Western Australia also spawn in winter, from May to September (Wakefield et al. 2010). Interviews with fishers identified a northward pre-spawning movement of hapuku in the South Island (Paul 2005b), with some suggestion that spawning occurs in or near Cook Strait (Hurst et al. 2000a). In the North Island there is some indication that an inshore movement is associated with spawning.

Egg and larval transport

There is no available information on hapuku. Based on the association of small pelagic juveniles with drifting seaweed (Roberts 1996), Wakefield et al. (2010) suggested that as with wreckfish, it is very likely that hapuku undertake pan-oceanic mixing between populations.

More generally, Peres & Klippel (2003) discussed the influence of oceanography on bass and hapuku around south-eastern Australia and New Zealand, and noted that the southeastern Australia continental margin was under the influence of the East Australian Current (EAC), a western boundary system. They argued that overall, western boundary current systems were a basic requirement for self-sustaining wreckfish populations, being the retention mechanism that diminished losses due to vagrancy. Within all self-sustaining wreckfish populations in the southwestern Atlantic, north Atlantic (Sedberry et al. 1999), and southwestern Pacific (including New Zealand), long migrations have been observed. The homing of adults to specific spawning sites produces a temporal persistence of larval

distribution in particular geographic places, as well as ensuring an available mate assemblage (Sinclair & Illes 1989). Peres & Klippel (2003) suggested that if this model was correct, the southwestern Pacific bass spawning grounds should be located somewhere between New Zealand and Australia, over continental or island slopes north of the Tasman Front.

Nursery habitats

The smallest hapuku juveniles are pelagic, potentially schooling in association with drifting seaweed. At 40–50 cm they become demersal and occupy water less than 200 m depth (Hurst et al. 2000a). Research trawls have captured small juvenile hapuku on the Stewart/Snares shelf and off the east coast of the South Island, and slightly larger juveniles on the Chatham Rise (Paul 2002a).

Australian industry has noted that small hapuku 2–5 kg form seasonal aggregations that can be targeted by trawl and non-trawl methods (Bruce et al. 2002). Paul (2002c) examined hapuku size data from research trawl surveys, and noted that small juveniles occurred on the Stewart–Snares shelf, and slightly larger juveniles on the Chatham Rise. Interviews with hapuku fishers found small juveniles reported from most regions but often localised in extent (Paul 2005b). Wakefield et al. (2010) in a study of hapuku life histories sampled fish down to 630 mm FL, which was considered early post-settled, allowing growth rates of pelagic juveniles to be extrapolated. Estimated growth rate during the pelagic life stage of hapuku was high, at 150–300 mm TL a year. Immediately post-settlement and between the ages of 2 and 5 years, growth slowed substantially to 15 mm year. The shift to benthic habitats was associated with a period of considerable change in their functional morph, including colour change, larger eyes, and rounder body shape, which consequently suppressed growth (in relation to length) in these early post-settled fish (Machias et al. 2003). This would explain the slower growth rates recorded at ages that corresponded to settlement (Roberts 1996; Francis et al. 1999). Following the transition associated with settlement and between the ages of 5 and 9 years, the period when hapuku matures, the growth rate increased to 40 mm a year. The growth rate then slowed to 4 mm per year, when all fish were mature (i.e. at 10 years) (Wakefield et al. 2010). These estimates of age and length at settlement agree with New Zealand studies (Roberts 1996, Francis et al. 1999); with Parker et al. (2011) finding that most small hapuku less than 65 cm TL, as sampled from an archive of otoliths from fisheries observer collections and research surveys around New Zealand, were aged 3–4 years.

Adult habitats

Anderson et al. (1998) looked at hapuku and bass distributions as shown by research trawl data, although it was noted that as both species prefer rougher seafloors, the sampling was incomplete (Paul 2002a). Hapuku were much more common on open seafloor than bass. Both species are found from Northland to Stewart Island, and across the Stewart and Snares shelf, and the Chatham Rise, with hapuku ‘stragglers’ extending south to the Auckland Islands. Hapuku are most abundant at 100–300 m water depth, peaking at 200 m; while bass are most abundant at 250–500 m water depth, peaking at 400 m.

Adult migrations and movements

Graham (1939a) described hapuku movements off the Otago coast, when shallow water populations were still present before heavy exploitation removed them. In May and June, ovaries matured, and fish undertook an outward migration into deeper water to spawn, where spawning occurred in July and August. In October and November a return movement occurred. He noted that in July and August the lower half of mature fish’s heads were scratched or scarred, and suggested that this was the result of preparing the seafloor for spawning, or from fighting at spawning time.

Beentjes & Francis (1999) tagged 1623 hapuku (124 returns, 16.3%) along the south-east South Island (SESI), Cook Strait (CS), and at the Poor Knights Islands (PKI), Northland (see Figure 10 below). Fish movements, as measured by point of recapture, ranged from the same areas as tagged (SESI 13%, CS 39%, PKI 40%), up to a maximum distance of 1389 km (two different fish), and 10.2 years at liberty.

Along the SESI coast, 918 hapuku were tagged and 130 (14.1%) recaptured. Tagged fish (tagged in 1988 and 1990) had length modes at 50–62 cm and 64–72 cm respectively, with an estimated 5% of tagged fish being sexually mature at release, and 13% at recapture (based on length frequencies, Johnston 1983a). All but one of the returns was from commercial fishers, with an average recapture depth of 76 m (range 22–402 m) and 88% from less than 120 m. The shortest time at liberty was 64 days, with over 60% of recaptures occurring after more than 400 days at liberty, up to a maximum of 2927 days (8 years). Sixteen (13%) were recaptured where they were tagged ('resident'), while 63% were recaptured within 50 km of the tagging site. Longer distance movers included 26 fish captured near Kaikoura, 6 in Cook Strait, and 4 around the North Island. The median distance moved was 18.5 km, but two fish travelled 1389 km, to Ninety Mile Beach and Tauranga respectively. Fish less than 70 cm were mainly recaptured near where they were tagged, although five fish travelled 215–481 km northwards within their first year at liberty (most or all of these fish would have been immature). Fish of 70–80 cm length displayed both short and long distance movement. Most fish longer than 80 cm at recapture (many likely to be mature) moved to Kaikoura or further north, although some were caught near the tagging site, and only one was at liberty for more than a year. It was concluded that time of liberty influenced the distance travelled by maturing/mature hapuku, but not by immature hapuku. The median distances travelled by hapuku under 70 cm, 70–80 cm, and more than 80 cm at recapture were 9.3 km (N = 56), 22.2 km (N= 27), and 342.6 km (N= 32) respectively (Beentjes & Francis 1999).

In Cook Strait, 599 fish were tagged between 1979 and 1984 (Johnston 1983a, b, 1992), and 116 (19.4%) returned. Tagged fish showed two length modes at 54–60 cm and 64–74 cm, with about 5% of tagged fish, and 30% of recaptured fish being mature. Only 13 (12%) fish were recaptured within 100 days of release, and 43% within 400 days of release. Thirty nine percent (43 fish) were recaptured where they were tagged ('resident'), and eighty four percent were recaptured within 50 km. Eleven fish were recaptured south of Cape Campbell, mainly around Kaikoura, with one return from Timaru (476 km). Only one fish moved north, to Napier. Length at recapture was not related to distance travelled, with the median distances travelled by fish under 70, 70–80, and more than 80 cm at recapture being 7.4 km (n=29), 6.5 km (n=35), and 3.0 km (n=47) respectively. The period at liberty also had little effect.

At the Poor Knights Islands, 106 fish were tagged (1987–1989 years) and 20 (18.9%) recaptured. Most tagged fish were between 70 to 94 cm length, with about 33% of tagged fish being mature, and 50% of recaptures. The average recapture depth was 93 m (23–200 m), with 60% between 80–100 m. Only two fish were recaptured within 100 days of release, with 65% made within 400 days, and 95% within 1000 days. No large scale movements were recorded, with 8 (40%) being made at the tagging site ('resident'), and 16 (80%) within 10 km of the tagging site, with the maximum distance moved being 51 km northwest to Cape Brett.

Beentjes & Francis (1999) concluded that there was considerable mixing of hapuku along the east coast of the South Island between Oamaru and Cook Strait, and that fish in this region probably formed a single stock. Hapuku tagged off the east coast South Island tended to migrate northwards, mainly from April to July, along a route that passed close to Kaikoura and into Cook Strait. Median

distance travelled increased with increasing length at recapture. Virtually all of the larger (more than 80 cm) fish tagged near Oamaru moved north within a year of tagging, suggesting that maturation and spawning may have been the trigger. However, some juveniles also moved several hundred kilometres northwards. The earlier arrival of spawning fish off Cape Campbell than in Cook Strait (Johnston 1983a) was also consistent with fish moving into Cook Strait from the south. Cook Strait hapuku were recaptured mainly between March and May, immediately prior to the spawning season, and the period of maximum fishery catches in Cook Strait. The influx of spawning fish to southern Cook Strait does not appear to continue north of the Brothers Islands (Johnston 1983a, b), suggesting that spawning occurs in southern Cook Strait, but the exact spawning location is not known. Spent fish occur in southern Cook Strait in October–November and then disappear in November (Johnston 1983a), indicating that hapuku disperse after spawning (Beentjes & Francis 1999). One hapuku in Cook Strait in 1979 was recaptured twice, in 1982 and 1984 at the tagging site, potentially indicating strong site fidelity, homing behaviour, or both. Beentjes & Francis (1999) concluded that as some hapuku moved large distances, and that commercial catches were strongly seasonal, with hapuku disappearing periodically from major fish sites (Johnston 1983a), that hapuku returned annually to specific spawning sites.

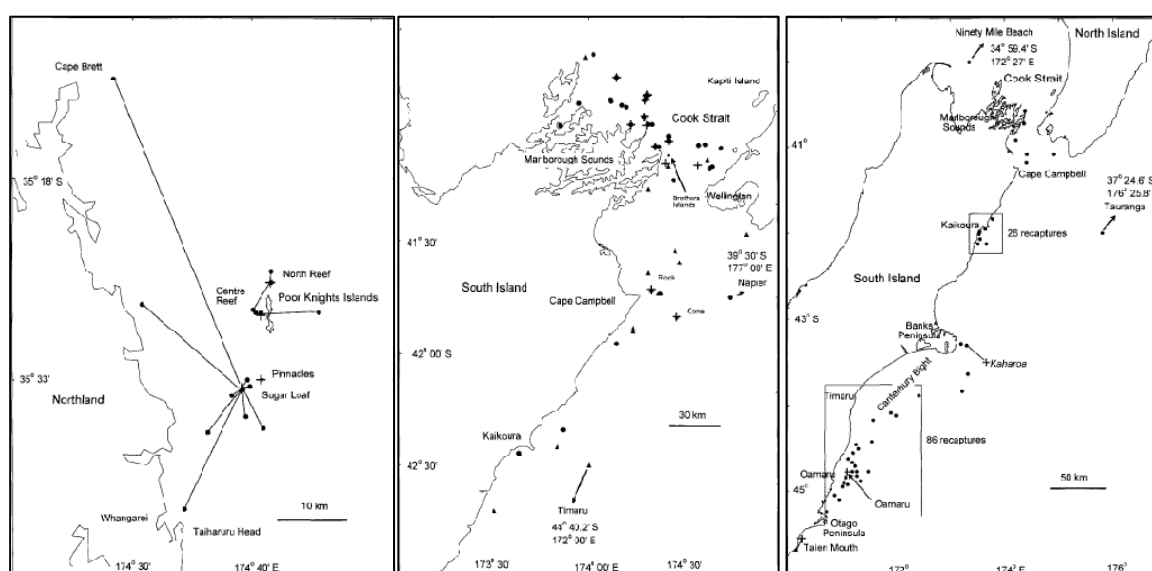


Figure 10: Hapuku tag and recapture locations, from Beentjes & Francis (1999), reproduced with permission. Left: Poor Knights Islands tag returns (N=20), tagging sites denoted with crosses and recaptures by dots, lines indicate direction and extent of movement. Centre: tag returns from Cape Campbell (N=24, triangles) and Cook Strait (N=87, dots) tagged fish, tagging sites denoted by crosses. Some dots denote multiple recaptures. Right: tag returns from southeast South Island (N=127) tagged fish, tagging sites denoted as x's. Recaptures from Taieri Mouth and R.V. Kaharoa are joined to their tagging sites by a line. All other black dots show recaptures of hapuku tagged off Oamaru. Some dots within the boxes denote multiple recaptures at the same site.

Paul (2002b) found differences in the seasonal timing of peak groper catches between northern and southern target fisheries, possibly indicating a north-south movement of one overall stock, although an alternative explanation was seasonal movements of fishers between groper and other more seasonally restricted fisheries. Paul (2005b) surveyed groper fisheries to assess whether such regional differences were from migration or different fishing patterns. Most fishers reported a fishing pattern of moving from ground to ground, 'resting' each for periods ranging from a week to a year, before fishing them again. There was general agreement that: large hapuku were removed first, possible

because of being locally dominant in their behaviour, and were fished down quickly, due to lower local numbers; that in some regions there had been a slow decline over decades in the average size of hapuku, and that in Cook Strait, there was probably little or no decline in catch rate during the peak May–July period, possibly as a consequence of migratory fish passing through. Many fishers inferred a northward movement of hapuku associated with spawning, at least along the east coast of the South Island and into Cook Strait, and a "disappearance" of fish, or a movement and/or dispersal into deep water as the roes became ripe.

Population connectivity

Paul (2002a) assessed information relevant to groper/bass stock structure in New Zealand, and concluded that the existing data was insufficient to quantify what stock structure might exist. He found discontinuities in distribution, and concluded that there was insufficient data to demonstrate differences in life history characteristics (e.g. size, growth, population age structure, age at maturity and spawning season) between locations. As knowledge of the location of spawning and nursery grounds was poor, and genetics did not indicate any differentiation within central New Zealand or between New Zealand and Australia (Ball et al. 2000), and juveniles have a pelagic (potentially highly dispersive) juvenile phase, he also concluded that this information suggested that a high degree of mixing might exist, and that there was little evidence for stock differentiation (Paul 2002b). At a more localised scale, interviews with fishers suggest that large hapuku were removed first and that this occurred quickly as there were few of them (Paul 2005b). The average size of hapuku also decreased in some areas. These observations and the behaviour of fish on 'resting' grounds, suggested that local short-term depletions were likely. The fact that fish on specific sites are replenished within a year suggests that there is a fair degree of mixing.

3.15 Jack mackerel (*Trachurus declivis*)

Fisheries catch:

Commercial: 40 031 t¹

Recreational: 80–110 t^{2*}

Sexual maturity: 26–30 cm / 2–4 years¹.

Maximum age: 28 years³

Pelagic phase duration:

Larval fish: 25+ days⁴(Tasmania)



Photo credit: M. Francis

¹MPI web site - for the 12 month period to 30/09/2011, all mackerel species combined; ² MPI Assessment Plenary Document 2012; *Harvest estimate for JMA 1. Estimates for other areas likely to be insignificant. See Plenary document for caveats around these estimates; ³ Paul (1992); ⁴ Jordan (1994)

T. declivis generally occurs in deeper waters (less than 300 m) than *T. novaezelandiae*, with temperatures of less than 16 °C and north of latitude 45°S (Annala et al. 2004). *T. declivis* is common around northern New Zealand, including the Kermadec and Lord Howe Islands (Francis 1993a) and is also found as far south as Stewart Island (Kawahara et al. 1988). *T. declivis* have been recorded in research and commercial trawls all around New Zealand and occasionally on the Chatham Rise, in mainly 30–300 m depth (Anderson et al. 1998, Bagley et al. 2000). In Australia this species is found from Shark Bay, Western Australia, to Wide Bay, Queensland, including Tasmania (Paxton et al. 1989). Australian fish are known to feed primarily on marine crustaceans, particularly euphasids

(krill) and copepods (Ward et al. 2012). Fish from deeper water have also been found to consume mesopelagic fish (Blaber & Bulman 1987).

Spawning

T. declivis is a serial spawner that spawns three batches of eggs at intervals of a month or more, resulting in a long spawning period (Horn 1991, Marshall et al. 1993). Reproductively active and spent fish are found in the central west coast area in spring (Horn 1991, 1993c), and east Northland area in summer (P. Taylor, NIWA, Wellington, pers. comm.). Eggs have also been recorded from the Taranaki Bight in January (Jones 1990), the Hauraki Gulf and east Northland (Crossland 1982). Spent fish have been recorded from the central west coast and (from one trawl tow only) off Southland (Hurst et al. 2000a). The proportion of actively spawning fish peaked in November, falling to about 20% from January to March. Most fish were resting from April to July, suggesting that spawning may be confined to spring and summer months (Hurst et al. 2000a).

Work on Tasmanian jack mackerel spawning suggested that the distribution of spawning was unaffected by inter-annual variations in oceanography, as the mature *T. declivis* populations spawn in deeper water, in the shelf-break region which is unaffected by potential warming of surface waters (Jordan et al. 1995). However, reproductive output may be affected by the availability of food in the year prior to spawning (Young et al. 1993, Jordan et al. 1995). Australian researchers also found that spawning occurred in a semi lunar cycle, with spawning peaks associated with both new and full moons (Ward et al. 2012).

Egg and larval transport

Small *Trachurus* are often found in association with floating objects such as drift algae, gelatinous zooplankton or flotsam (Kingsford 1993) and are probably not well sampled by bottom trawls. Eggs are known to be positively buoyant (Ward et al. 2012). Australian researchers found larvae of *T. declivis* between spring and summer, which matched the seasonal gonadal staging of adults (Webb 1976, Stevens et al. 1984, Ward et al. 2012). Investigation of this species in Australian waters has identified that eggs and sperm are released amongst schooling fish, with eggs generally distributed between the surface and the thermocline and subsequent larvae being carried inshore by currents (Kailola et al. 1993).

Juvenile habitats

Juveniles have been recorded from the North Taranaki Bight (1+) in 125–150 m depth, off the central west coast and about 300 miles northeast of East Cape (Jones 1990, Horn 1991, 1993c). The distributions of 0+, 1+, and all juveniles combined are consistent with known spawning areas. They occur mainly around the North Island, with a few off the northern parts of the South Island, in up to 200 m depth. Adults have been caught also on the Chatham Rise and off Southland, down to about 350 m depth. Juvenile *T. declivis* have been caught on *Kaharoa* trawl surveys around the North and South Islands, mainly over the mid shelf. Off the south-west North Island, catch rates peaked at 0.1 t.km⁻², while the highest catch rates in Tasman Bay was also 0.1 t.km⁻² (Hurst et al. 2000a).

Adult habitats

Jones (1990) suggested that smaller jack mackerel (up to 25 cm) occur in surface waters both inshore and offshore, and that the large fish are found nearer the bottom in offshore waters.

Adult migrations and movements

There has been some stock assessment work directed at *T. declivis* in Australia (Ward et al. 2012). A correlation between size and depth is apparent, with smaller fish generally being found inshore and


larger fish offshore (Shuntov 1969, Kailola et al. 1993, Stevens et al. 1984, Pullen 1994). These size dependent distributions suggest offshore movement with increasing size (Ward et al. 2012).

Population connectivity

The essentially mobile behaviour of jack mackerel has led to the hypothesis that a single stock for jack mackerel exists around New Zealand (with a separate stock of *T. murphyi*). However, recent research into blue mackerel and kingfish has indicated a west coast North Island, versus east coast North Island stock structure split, suggesting the need for further research into the working hypothesis for jack mackerel (McKenzie 2009).

An extensive review of available data for Australian jack mackerel by Bulman et al. (2008) led to the conclusion that eastern Australia and eastern Tasmania were likely to be a separate sub-population to fish west of Tasmania including the Great Australian Bight and Western Australia (Ward et al. 2012).

3.16 Jack mackerel (*Trachurus novaezelandiae*)

<p>Fisheries catch: Commercial: 40 031 t¹ Recreational: 80–110 t^{2*}</p> <p>Sexual maturity: 26–30 cm / 3–4 years¹</p> <p>Maximum age: 25 years³</p> <p>Pelagic phase duration: Larval fish: 25+ days</p>	 <p>Photo credit: C. Duffy, DOC</p>
<p>¹MPI web site - for the 12 month period to 30/09/2011, all mackerel species combined; ² MPI Assessment Plenary Document 2012; *Harvest estimate for JMA 1. Estimates for other areas likely to be insignificant. See Plenary document for caveats around these estimates; ³Annala et al. (1994); ⁴Syahailatua (2005).</p>	

The jack mackerel *T. novaezeandiae* is common around northern New Zealand (Kawahara et al. 1988), including the Kermadec and Lord Howe Islands (Francis 1993a), and is also found from Western Australia to New South Wales. In Australia this species extends slightly further north than the distribution of *T. declivis* (i.e. Shark Bay, Western Australia; to Wide Bay – Queensland), but rarely reaches Tasmania (Ward et al. 2012). *T. novaezelandiae* have been recorded in research and commercial trawls, mainly around the North Island and occasionally around the northern South Island. They occur mainly from inshore out to 200 m depth (Anderson et al. 1998, Bagley et al. (2000).

Spawning

T novaezelandiae is a serial spawner with a protracted spawning season (Horn 1991). Reproductively active and spent fish have been found in the central west coast area in spring and east Northland in summer (Horn 1991, P. Taylor, NIWA, Wellington, pers. comm.). Gonad state has been recorded only from the central west coast of New Zealand (FMAs 7, 8 and 9). Ripe, running ripe and spent stages have all been found. The proportion of actively spawning fish peaks in November but is also about 20% in February. In March, about 20% of fish are spent. The months on either side of November have not been sampled so the full extent and peak are not well determined. Most fish were resting from May to July, suggesting that spawning may be confined to spring and summer months (Hurst et al. 2000a).

Spawning also occurs in the Hauraki Gulf in spring/summer (Crossland 1982), and off East Northland (e.g. outer Bay of Islands, off Bream Head and in Exhibition Bay) (Crossland 1982), as well as other northern areas of New Zealand.

Egg and larval transport

Eggs have been recorded from the inner and outer Hauraki Gulf in spring-summer (Crossland 1982), off east Northland, particularly the outer Bay of Islands and off Bream Head in October-December, and in Exhibition Bay in December (Crossland 1982). Larvae are very abundant in the Hauraki Gulf, close to the eggs, but displaced a few miles, and peaking in November (Crossland 1981a). Larvae were recorded, but not common, in east Northland (Crossland 1982). They have also been taken in plankton tows in the South Taranaki Bight (Jones 1990). Australian researchers have identified that eggs and sperm are released amongst schooling fish, possibly deep in the water column near the edge of the continental shelf. Eggs are distributed between the surface and the thermocline and larvae are carried inshore by currents (Kailola et al. 1993). Eggs of this species are positively buoyant (Ward et al. 2012).

Juvenile habitats

Small *Trachurus* are often found in association with floating objects such as drift algae, gelatinous zooplankton or flotsam (Kingsford 1993) and may therefore not be well sampled by bottom trawls. Juveniles have been caught in Wellington Harbour, Pauatahanui - Porirua inlets, Tasman Bay, Golden Bay, South Taranaki Bight, Bay of Plenty and Hauraki Gulf and in the central west coast area (Healy 1980, Jones 1990, Horn 1991). The distributions of 0+, 1+, and all juveniles combined are consistent with known spawning areas and the distribution of the adults. They occur mainly around the North Island, with a few off the northern parts of the South Island, in up to about 150 m depth (Hurst et al. 2000a). Juvenile *T. novaezelandiae* have been caught on *Kaharoa* trawl surveys around the North and South Islands, mainly in inshore and mid shelf areas. Around the northern North Island, juveniles catch rates peaked at 3.4 t.km⁻² inside the Hauraki Gulf. Off the south-east coast of the North Island, juveniles catch rates peaked at 0.3 t.km⁻² off East Cape. Around the South Island juvenile abundance was highest in Tasman Bay, reaching 0.4 t.km⁻² (Hurst et al. 2000a).

Adult habitats

T. novaezelandiae is found predominantly around the North Island in waters shallower than 150 m (including estuaries) and warmer than 13 °C; it is uncommon south of latitude 42°S (Annala et al. 1994, 2002). They are commonly found near the bottom or in mid-water (Armitage et al. 1994). Adults are often found over offshore rocky reefs while juveniles are predominantly found in shallow soft substrate habitats (Kailola et al. 1993).


Adult migrations and movements

No information is available.

Population connectivity

Horn (1993c) identified geographical variation in growth of *T. novaezelandiae* in New Zealand, with fish from the Bay of Plenty growing significantly faster than those from the west coast. A large proportion of the *T. novaezelandiae* catch in New Zealand consists of fish larger than 30 cm FL and greater than 10 years old (Horn 1991, Taylor 1998). Further, the size composition of landings in New Zealand have also been shown to vary spatially, possibly because of size-related differences in migrations, or because of the presence of more than one subpopulation. Market preferences however may confound such interpretations, with fishers targeting schools of particular sized individuals to maximise their market returns.

3.17 Murphy's mackerel (*Trachurus symmetricus murphyi*)

<p>Fisheries catch: Commercial: 40 031 t¹ Recreational: 80–110 t^{2*}</p> <p>Sexual maturity: Unknown</p> <p>Maximum age: 32 years¹</p> <p>Pelagic phase duration: Larval fish: 55 days³</p>	
<p>¹MPI web site - for the 12 month period to 30/09/2011, all mackerel species combined; ²MPI Assessment Plenary Document 2012; *Harvest estimate for JMA 1. Estimates for other areas likely to be insignificant. See Plenary document for caveats around these estimates; ³Taylor (2002).</p>	

Murphy's mackerel (also known as the Chilean or Peruvian mackerel) invaded New Zealand waters from South America. It was first observed in the mid-1980s and established a local spawning population (Taylor 1999a). They have been recorded in research and commercial trawls, mainly around the South Island, the Chatham Rise and southern North Island, and occasionally at the Auckland Islands, in 30–400 m depth (Anderson et al. 1998). Their extent around the northern North Island is not well determined by trawl surveys as jack mackerel are not always identified to species level, but they have been recorded off the north-east coast of the North Island from aerial sightings (Bagley et al. 2000).

Spawning

Fish in maturing or spawning condition have been caught by trawl or purse-seine in the Bay of Plenty, east coast of Northland, central west coast area, part of the west coast of the South Island, the Stewart/Snares area, and on the Chatham Rise (Taylor 1999a). Gonad state has been recorded mainly from the central west coast of New Zealand and Southland, with occasional records from the Chatham Rise and the Auckland Islands. Ripe, running ripe and spent fish have been recorded from all these areas except the Chatham Islands. Seasonally, the best coverage is from the central west coast (FMAs 7, 8 and 9). The proportion of actively spawning fish exceeded 20% in July, September, and from December to February, and most fish during these months were maturing. It is likely that most fish sampled in July came from the west coast South Island (from the hoki fishery) and the later spawners came from the south Taranaki Bight Area (Hurst et al. 2000a). The highest proportion of spent fish occurred in February and resting stage fish dominated in May and June. This suggests that spawning occurs from late winter through to summer. Across the Chatham Rise (FMAs 3 and 4), spawning activity peaked in November (about 60%) and there was some evidence of activity through to April. Spawning activity during winter/early spring was not able to be determined. Off Southland and the Auckland Islands, samples are from December to April. Most fish were resting although maturing fish were present from January to April. The extent of spawning activity in these areas was not well determined from these data (Hurst et al. 2000a).

Egg and larval transport

Eggs and larvae of the Chilean mackerel have been found over 1000 km from the Chilean coastline (cited in Bailey 1989).

Juvenile habitats

Juveniles of less than 30 cm have been recorded in research trawls from the east coast of the North Island, South Taranaki Bight and a few from the west coast South Island (Taylor 1999a). The few records of immature fish are mainly from around the central North Island, with a few from around the South Island and the Chatham Rise, and off Southland, in up to about 350 m depth. There is some evidence that the east coast of the North Island is an important nursery area for early life history stages of *T. murphyi* (Taylor 2004).

Adult habitats

Adults are caught in similar areas as juveniles, but also occur further north, as well as more extensively across the Chatham Rise (Hurst et al. 2000a).

Adult migrations and movements

No information is available.

Population connectivity

Taylor (2002) investigated the biology of *T. murphyi* to establish whether a self-sustaining stock had established in New Zealand waters. Comparisons of sea surface temperature, distributions of the most preferred prey items of *T. murphyi*, and simulations of the effect of coastal transport mechanisms on eggs, larvae, and juveniles, identified that New Zealand waters are conducive to stock establishment. Taylor noted that spawning adults have been identified from a number of different areas around New Zealand, and that small juveniles have been collected from the South Taranaki Bight and the East Cape-Mahia area. In 2002 the New Zealand population of *T. murphyi* consisted mainly of individuals that have invaded New Zealand waters, with a small but increasing proportion that may be the result of local spawning. An investigation of the geographic distribution of Murphy's mackerel catches over time showed an initial appearance around the Chatham Islands in 1984–85, a westward expansion from 1986–87 to 1994–95 as catches increased, followed by an eastward contraction to 2006–07, as catches declined (Penney & Taylor 2008). Taylor (2002) concluded that *“Most of this information supports the hypothesis that T. murphyi in the New Zealand region are a small, and perhaps periodically separated, component of a larger South Pacific stock which undergoes periodic expansions or migrations”*.

In a study of otolith chemistry from Chilean *T. murphyi*, Ashford et al. (2011) concluded that rather than discrete populations separated by boundaries, their results suggested a complex spatial structure for this fish stock *“defined by environmentally mediated survival and connectivity”*. They hypothesised that fish caught off New Zealand may be of South American origin; and that the spawning zone off central Chile may supply fisheries around the South Pacific. They also suggested that the *“distributions of eggs and larvae across the center of the South Pacific Gyre suggest further spatial structuring by transport”*. *T. murphyi* mackerel spawned further south were more likely to be entrained into the West Wind Drift, whereas those to the east and north were more likely to be retained in oceanic waters. Ashford et al. (2011) further suggested that mortality and diminishing migration of Murphy's mackerel along the Subtropical Front might lead to extinction and prevent re-colonisation of fishing grounds around New Zealand.

There have been several stock structure hypotheses for *T. murphyi* fisheries and up to four separate stocks have been suggested: a Chilean stock; a Peruvian stock; a central Pacific Ocean stock and a south-west Pacific Ocean stock. However, genetic work did not support these suggested divisions well (Cárdenas et al. 2009).

3.18 John dory (*Zeus faber*)

Fisheries catch

Commercial: 637 t¹

Recreational: 75–303 t^{1*}

Sexual maturity: Females: 29–35 cm / 2 years¹, or 35–40 cm / 5 years², males: 23–29 cm / 2 years¹, or 30–35 cm / 4 years²

Maximum age: 9 years / 40 cm³ or 12 years / 60 cm⁴

Pelagic phase duration:

Eggs: 12–14 days to hatch¹

Larvae: Unknown

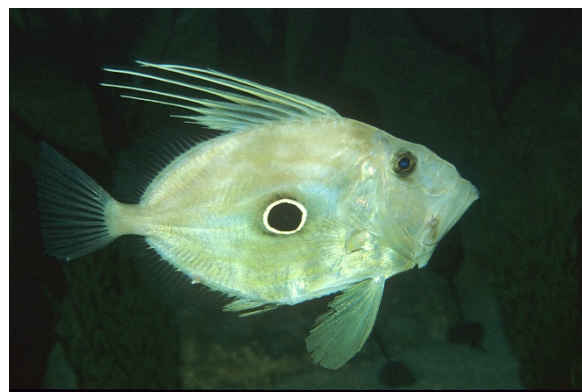


Photo credit: M. Francis, NIWA

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 2, 2012; *Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²Francis (2001); ³Hanchet et al. (2001); ⁴Smith & Stewart (1994).

John dory have a worldwide distribution in temperate waters of the eastern Atlantic, Mediterranean, Western Pacific and Indian oceans, although the northern and southern hemisphere populations are very genetically distinct (Ward et al. 2008). This includes Australia, ranging from the central coast of Western Australia, around the south of the country, and as far north as southern Queensland (Gomon et al. 1994), down to water depths of 150 m. John dory occur throughout New Zealand from Three Kings to Foveaux Strait and around the Chatham Islands out to 200 m, but are most common in less than 50 m water depth (Anderson et al. 1998, Bagley et al. 2000, Hurst et al. 2000a). They are common in the inshore coastal waters of northern New Zealand, to a lesser extent in Tasman Bay, and generally uncommon south of Cook Strait. This northerly distribution is reflected in the 50–65% of annual commercial catch taken in JDO 1, where it is caught as a bycatch in most trawl and Danish seine fisheries targeted at the main inshore species (MPI 2012). Usually a solitary fish, John dory are daytime hunters, taking advantage of their body shape by stalking their prey from behind (Francis 1996). They are largely piscivorous, even from a small size feeding on small baitfish demersally and in mid-water (Stergiou & Fourtouni 1991, Velasco & Olaso 1998, Choi et al. 2011). However, this is preceded by an initial period after settlement of feeding on small crustaceans and copepods (fish less than 6 cm, Choi et al. 2011).

Spawning

John dory spawn serially over a long season (Hore 1982, 1985) across a wide part of their distribution. In the Hauraki Gulf, spawning occurs between December and March (Hore, 1982), and this timing also probably holds for the north-eastern New Zealand coast more generally. Running ripe females have been caught in mid shelf depths between East Cape and Cape Runaway between March and April (D. Robertson, pers. comm., in Hurst et al. 2000a) and Tunbridge (1966b) reported ripe females in catches from January through to as late as August along the west coast of the North Island. Data collected from monthly commercial catch landings reported maturing fish in October to November, and ripe and running ripe fish through the summer months (peaking in February), from the northern North Island, with a few records in Hawke Bay and south Taranaki Bight (Hurst et al. 2000a). Horn et al. (1999) estimated that in JDO 1 and 2 through the summer months an average of 40–50% of commercial catch was landed during the spawning season. Danish seiners target small aggregations in the Hauraki Gulf seasonally, but it is not known if these are related to spawning. Spawning may occur

in pairs or in mid-water aggregations (Morrison 1996). The scarcity of observations in general of large catches of ripe fish in New Zealand waters suggests that John dory do not form large spawning aggregations (Dunn & Jones 2013). Dunn & Jones (2013) interviewed eight John dory fishers: some reported ripe John dory in the western Bay of Plenty in autumn, in spring (November/December) on the west coast of the North island, and in the summer months from the end of December onwards along the east coast of the North island (JDO 2 east). No regular and important spawning sites were identified for John dory, although one fisher believed they did “*school up to spawn*”. On the west coast, spawning fish were thought to move into shallower water and were caught all along the coast (Dunn & Jones 2013).

Egg and larval transport

John dory have large pelagic eggs which take 12–14 days to hatch (Hore 1985). Robertson (1975) reported the presence of eggs from plankton samples between spring and autumn. However, Hore (1982) found no eggs or larvae in his 31 stations in the Hauraki Gulf, while Crossland (1982) found only a few eggs and one juvenile in his sampling in the Hauraki Gulf, mostly in outer gulf stations, as well as a few taken in stations near Bream Head. Tricklebank et al. (1992) did not report any John dory larvae from a year of near-shore neustonic (sea surface) larval sampling off Leigh, in the outer western Hauraki Gulf.

Nursery habitats

Small 0+ juveniles down to 5–10 cm have been caught in inshore trawl surveys around the North Island from March onwards, reaching 20 cm by December (Hanchet et al. 2001). A small mode of 1 year old fish was consistently present in all surveys; Bay of Plenty 22–28 cm (Oct–Nov), Hauraki Gulf 12–25 cm (Feb/March), and west coast North Island 10–25 cm (Oct–Nov) (Horn et al. 1999, Morrison et al. 2001a). Stevenson (1998) provided abundance distribution plots for juvenile John dory by survey area (1983–1997 surveys), indicating that they were wide-spread and most abundant in 50–100 m water depth. In the Hauraki Gulf, particularly high catch rates were sometimes recorded around the inner gulf islands, Firth of Thames and western Coromandel coast (maximum 0.3 t km⁻²). In the Bay of Plenty, high catches were recorded from 25–100 m, with some stations offshore from Tauranga yielding especially high estimates in some years. Catch rates were less consistent on the west coast, although high off Ninety Mile Beach in a number of years. On the east coast lower North Island, catch rates were much lower (max of 15 kg km⁻²) with most John dory being caught north of Cape Kidnappers. Around the South Island juveniles are caught mainly in Tasman Bay (up to 36 kg km⁻²) (Hurst et al. 2000a).

These trawl survey data offer no indication of the habitat associations of these smaller 0+ and 1+ fish, especially at the finer biotope scale. Bradstock & Gordon (1983) noted that fishers trawling off the north coast of the South Island “*were quick to observe, in certain areas, the association of juveniles of important commercial fish with abundant clumps and mounds of 'coral'.*” John dory was one of the species noted, and this suggests that as with other species such as snapper and blue cod, juveniles may be more abundant in areas with biogenic structure such as bryozoans (e.g. Separation Point, Vooren 1975, Bradstock & Gordon 1983). Small juvenile John dory do not appear to be seen often by divers, suggesting that they occur at depths and/or habitats not accessed by recreational divers. However, small juveniles with the long trailing fin structures of recently settled fish have been seen in low numbers (approximately a dozen), as scattered individuals on exposed shallow water reefs (14–20 m) off Te Arai Pt., Pakiri Beach, Northland (M. Morrison, pers. obs.).

Dunn & Jones (2013) reported from their John dory fisher interviews that fishers in all areas caught small John dory (Hauraki Gulf, western Bay of Plenty, south east coast of the North Island, northern west coast of the South Island and Golden and Tasman Bays). Observed numbers were usually low, although one west coast North Island fisher reported catching “*heaps and heaps*”, observing small fish falling out of the cod end meshes and being picked off by seagulls. Juvenile John dory sizes ranged down to 10–15 cm, although one mentioned catching fish 3–4 cm long. One fisher reported catching small (15–30 cm) fish in deeper water (180 m) at night, with larger adults caught in shallower depths (60–79 m). Most fishers reported that the juveniles were caught along with adult fish, but some areas were highlighted as possible nursery grounds. These included: an area about 5 miles (40–50 m depth) north of The Noises Islands in the Hauraki Gulf, an area near Great Mercury Island in the western Bay of Plenty; and the bays along the coast towards Cape Turnagain, lower east coast North Island, although one fisher commented that “*you don’t catch many small fish in Area 2*”; and north of Kapiti Island and “*on the edge of the weedline*”, on the southwest coast North Island (Dunn & Jones 2013). Note was also made of a strong year class being tracked in the Golden and Tasman Bays region, where fishers observed an increase in John dory, starting in 1999–2000, with increasing numbers of smaller fish (5–10 cm) initially caught in dredges, and then in subsequent years larger numbers of medium sized (about 35 cm), and then larger fish, being caught (Dunn & Jones 2013).

Adult habitats

John dory are considered to have a locally patchy distribution and utilize a range of habitats from open sand and muddy grounds as well as rock structures and reefs. Diving and recreational forums frequently report that John dory are common around kelp beds and other “*weedy areas*”, often found at the edges of these areas where their body shape and colouration ensures that they are well camouflaged. Trawl surveys around northern New Zealand consistently catch John dory, although catches are always small, and patchy and erratic in their distribution. In the Hauraki Gulf, the highest catches were found in the inner Gulf between Kawau and Rangitoto Islands, the southeast of Waiheke Island, in the outer Firth of Thames (Langley 1994, Morrison et al. 2002). In Northland, surveys in the early 1990s recorded highest catch rates within the Bay of Islands (Langley 1994), with similar patterns observed more recently (Bay of Islands OS 2020 unpubl. data). Off the west coast North Island, John dory were caught throughout the survey area with highest catches recorded in the 50–100 m depth stratum, particularly off Ninety Mile Beach, and between the Waikato River and Cape Egmont in some years (Langley 1994). An early exploratory trawl survey between Cape Egmont and Cape Farewell found John dory across the whole area (Tunbridge 1966b). In the Bay of Plenty it occurred in 62–84% of all trawl stations in low numbers (Morrison et al. 2001b) with higher catches noted between Great Mercury and Motiti Islands (Langley 1994). Along the south-east coast of the North Island, catches increased north of Cape Kidnappers (Stevenson & Hanchet 2000a). Trawl surveys on the east and west coast of the South Island record the species in very low numbers along the east coast (only three were caught in the most recent survey, Beentjes et al. 2010a), but higher numbers in Tasman Bay and west coast South Island surveys (Stevenson 2007), particularly in the last 10 years. Along with increased JDO 7 landings (more than 100 t since 2000), this change is thought to be from increasing abundance in response to environmental influences and stock displacement in this area (MPI 2012).

Dunn & Jones (2013) reported that fishers in the Hauraki Gulf, Bay of Plenty, northern west coast (JDO 1) and lower east coast of the North Island (JDO 2) all reported catching John dory all year around at low levels. Some areas were noted as providing higher catches, including certain soft muddy bottom areas, around rocky outcrops and rocky reefs, and algal-covered banks. John dory were

caught throughout Tasman and Golden Bay, Cook Strait and Cloudy Bay, with the main area being around Farewell Spit and Kahurangi Shoals, with catches often greater over rougher ground.

In the Mediterranean, Maravelias et al. (2007) found that water depth, temperature and latitude were key determinants of distribution, with John dory preferring warmer, shallower, waters (less than 80 m), particularly in autumn/winter, and a seasonal pattern of habitat associations for specific locations characterised by weak near-bed currents, and associated sand wave development. Three main aggregation areas were identified. These areas were also close to a strong southward current hydrographic regime which, it was suggested, enhanced the food supply. The authors concluded that the seasonal spatial patterns observed were probably driven by spawning in the summer, and a focus on feeding in the autumn/winter. These behaviours may also apply to New Zealand populations.

Adult migrations and movements

Very little is known about John dory movement. It has been noted that adults move out into deeper water in the Hauraki Gulf in summer, with a shallower inshore distribution in winter; a similar inshore movement is reported anecdotally in Australia (http://www.mesa.edu.au/AtoZ/John_Dory.asp). This pattern of movement was also reported by Maravelias et al. (2007) in the Mediterranean, where John dory are believed to move between a small number of sites to spawn and feed over a scale of hundreds of kilometres. Annala et al. (2004) noted feeding aggregations over winter, behaviour also reported from the Mediterranean (Maravelias et al. 2007).

Dunn & Jones (2013) reported that Hauraki Gulf fishers returned their highest catches in the cooler months either side of summer and in early winter, although abundance was reported as very variable. Fishers believed variability in John dory catches was mainly related to the abundance of prey (baitfish: sardines and pilchards, maybe juvenile snapper), for which the John dory would aggregate, sometimes in great densities. On the west coast of the North Island, late winter, spring and early summer (Aug/Sept and Nov/Dec) were good catch months; while in the western Bay of Plenty, highest catches were thought to occur in autumn. In the Hawke's Bay region, trawl catches were generally highest in mid-summer, between mid-January and mid-March. Summer was also reported as the time for higher catches in JDO 7 (Golden and Tasman Bay), over a 3–4 month window, and at depths of 20–25 m. Most fishers commented on how John dory were quite unpredictable and could “*just turn up*” and disappear very quickly. Hauraki Gulf Danish seiners believed that fish were moving through their fishing area in response to the presence of prey. Fishers in other areas didn't believe John dory moved far, but catches were reduced when the fish moved off the bottom, making them unavailable to the trawl or Danish seine nets. In the western Bay of Plenty, John dory were caught with stomachs full of “*red-coloured eel-like fish, around 10–12 cm long*” (probably red bandfish *Cepola haasti*; Peter McMillan, pers.comm.; also observed for John dory and snapper in East Northland during the OS2020 BOI trawl survey, M. Morrison, pers. obs.), and the fisher believed that John dory descended to the seafloor at certain times of the day to feed on these (this species lives in burrows). It was also thought that John dory may move into shallower water at some times of the year and onto hard ground, with their presence noted around wharf pilings, in shallow bays and at reef sites such as Waihi Bluffs in the Bay of Plenty, Clive Hard, Hawke Bay, and around Kapiti Island. One fisher reported being able to pick up adult live John dory from the beach, believing that they accidentally became beached following baitfish into the shallows. All fishers believed the John dory were likely to be resident in the areas where they fished, and thought absence in catches was due to moving to localised areas or into midwater, where they were less available (Dunn & Jones 2013).

Population connectivity

There are no genetic population studies for this species in New Zealand waters but given that this is a short-lived and fast growing species, it seems likely that localized populations exist; maintained by feeding, spawning and juvenile nursery habitats on a relatively local scale, with some evidence that biogenic habitat areas may be important in the juvenile stage. A recent review of John dory stock structure and fishery characterisation suggested five stocks: (1) Hauraki Gulf and east Northland, (2) Bay of Plenty, (3) West coast North Island, (4) Southeast North Island, and (5) Northern South Island. As John dory have been caught around most of the North Island and northern South Island of New Zealand, it was noted that the the boundaries between the assumed stocks were not distinct (Dunn & Jones 2013).

3.19 Kahawai (*Arripis trutta*)

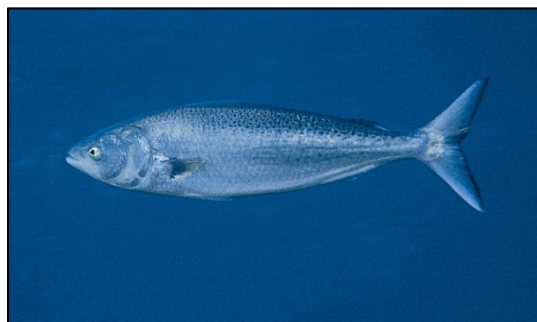
Fisheries catch:**Commercial:** 2221 t¹**Recreational:** 1000–1500 t^{1*}**Sexual maturity:** 40 cm / 3–4 years^{1,2}**Maximum age:** 26 years¹ / 79 cm³**Pelagic phase duration:****Eggs:** Unknown**Larvae:** Unknown

Photo credit: M. Francis, NIWA

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 2, 2012; *Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates;

²McKenzie NIWA, unpubl. data; ³Duffy & Petherick (1999).

Kahawai are found throughout New Zealand waters (29° to 46° S) from the Three Kings and Chatham Islands to Foveaux Strait, but are more common around the North Island and on the east coast of the South Island (Hurst et al. 2000a). Kahawai are also found in Australia, from the Tweed Heads in New South Wales to Port Phillip Bay in Victoria, and in Tasmania (Morton et al. 2005) where they are commonly called Australian salmon. The kahawai population in Australia is considered to be geographically distinct from fish stocks in New Zealand. There is also a far less common second species of kahawai in New Zealand, the Kermadec kahawai (*Arripis xylabion*), which is distinguished solely by a larger caudal fin (Paulin 1993). This species grows considerably bigger than kahawai (to at least 94 cm) but beyond this little is known about its biology. Although Kermadec kahawai are most abundant around the Kermadec Islands, they are also occasionally caught off northern New Zealand. Both species are currently combined under the species code KAH for the purposes of fisheries management, but almost all available literature refers to *A. trutta*.

There is a considerable amount of literature and anecdotal information on the diet and feeding behaviour of kahawai in New Zealand (Graham 1956, Moreland 1960, Baker 1971, Penlington 1988). Juvenile kahawai smaller than 100 mm are known to feed mainly on planktonic crustaceans (Baker 1971, Lowe 2013) in shallow coastal waters, with some seasonal variation in prey composition occurrence and quantity. Kahawai are opportunistic carnivores feeding on the most readily available food (Penlington 1988) which varies with season (Graham 1956). Feeding behaviour can be largely divided into two different generic feeding types. Catches of large adult kahawai from offshore coastal surface schools have been observed to feed on pelagic crustaceans, especially krill (*Nyctiphanes*

australis) (G. Plowman, Sanford Ltd, pers. comm.) gorging themselves to fullness, and competing with other pelagic species such as jack mackerels (*Trachurus* spp) and scombrids (*Katsuwonus* spp., *Scomber* spp., *Thunnus* spp.) (Bailey 1983, MPI unpubl. data).

In contrast, inshore schools of adult kahawai predate mainly on geographically common pelagic fish species, such as anchovy (*Engraulis australis*), pilchard (*Sardinops neopilchardus*), sprat (*Sprattus* spp), yellow eyed mullet (*Aldrichetta forsteri*), garfish (*Reporhamphus ihi*), and jack mackerel, especially in late summer and autumn. Such surface feeding forays are often seen in association with large numbers of terns and gulls (Baker 1971). However, the occurrence of demersal fishes; ahuru (*Auchenoceros punctatus*), sole (*Peltorhamphus novaezeelandiae*), opalfish (*Hermerocoetes monopterygius*), triplefins (*Tripterygiidae*), freshwater bullies (*Gobiomorphus* spp.), and crustaceans in kahawai stomachs is further evidence of bottom feeding (Moreland 1960, Baker 1971, Penlington 1988) as is the regularity with which fish are caught by recreational anglers fishing with baits directly on the seabed, especially close to shore. Finfish species were the most common prey item found in the stomachs of kahawai caught in Wellington Harbour, with the incidence of the second most common prey type, euphausiids, peaking during winter months (Baker 1971). Kahawai with stomachs full of pilchards are commonly caught by set net and ring net fishers targeting subsurface schools during nocturnal winter sets in the Hauraki Gulf. Estuarine fish studies have shown that adult kahawai feed in large estuaries throughout the year (Webb 1973, Kilner & Ackroyd 1978). Examination of kahawai stomachs caught from the Motu River mouth showed that in November 50% of fish contained traces of food, but by April this had declined to 1% (Penlington 1988). Collectively, these data show that kahawai exploit a range of feeding niches.

Spawning

The spawning habitat of kahawai is unknown but is thought to be associated with the seabed in deeper offshore waters. Schools of females with running ripe ovaries have been caught by bottom trawl in 60–100 m in Hawke Bay (Jones et al. 1992). Other females with running ripe ovaries have been observed in east coast purse seine landings sampled in March and April 1992, and between January and April in 1993. Crossland (1982) collected eggs from the outer Hauraki Gulf in February. A survey on kahawai caught from the Motu River mouth (Bay of Plenty) from November 1982–April 1983 suggests that the highest proportions of fish with mature gonad stages occurred in February (65%), dropping to 4% by April, when 75% of mature fish were classified as reabsorbing (Penlington 1988). Spawning therefore probably occurs around February, in the north at least. Most anecdotal reports of catching large kahawai spawning on the seafloor are associated with deeper waters, such as the following comment made by an ex-commercial fisherman:

“Years ago kahawai in the outer gulf were big and abundant around both barrier islands and the Mokohinau Islands. There was a seasonal component I recall in the early 1980s when for a month or so around March (I think?) for several years we were catching very large kahawai on the bottom on commercial longlines while targeting big gurnard for the Iki market and snapper in 50 to 70 meters out from Catherine Bay Gt Barrier. Some days the kahawai would be 70% of the catch.” (Paul Barnes, extract from an interview documented in Hartill & Walsh 2005).

Some spawning may also occur closer to land in deep embayments.

“Spawning appears to occur in autumn in the Bay of Islands. The run of large mature kahawai into the Bay of Islands from February through to March is one of the few kahawai ‘runs’ that can presently be relied on. These are spawn ready fish that hang around in the Bay of Islands area for several months after spawning. Where they come from and where they go to is unknown. Kahawai

that have recently finished spawning have been observed in the Cape Brett region in late April.” (Craig Worthington, Marine Aquarium Collector, extract from an interview documented in Hartill & Walsh 2005).

Length-maturation data collected from thousands of kahawai samples in the early 1990s suggest that the onset of sexual maturity occurs in males at around 39 cm and in females at 40 cm (McKenzie, NIWA, unpubl. data) which closely matches an estimate of 39 cm used for Australian *A. trutta* (Morton et al. 2005). This length roughly corresponds to fish of four years of age in both countries. Drummond (1994) found little or no gonad development in fish smaller than 33 cm at any time and suggests that although this may represent the onset of sexual maturity, it is unlikely that these fish have become sufficiently developed to spawn in the same year. This study also found that similar proportions of males and females were present in purse seine catches. Egg counts carried out in the 1970s (MAF Fisheries unpubl. data) showed that female kahawai produce 60 000 to 750 000 eggs, depending on the size of the fish examined.

Egg and larval transport

Little is known of the early life history of kahawai, as very few were encountered when larval fish surveys were carried out around New Zealand in the early 1970s by Robertson (1973). Small pre-settlement juveniles are sometimes observed on the open coast about 3–4 months after the spawning season. *“By June post-larval kahawai are present in their thousands along the current lines and wind lanes in the waters slightly offshore of Urupukapuka Island and Cape Brett. These juveniles are bright blue and silver with eight or nine dark bars on their back. There are two reflective patches above their lateral line that shine silver when observed from above. Seen in the water these patches are noticeable as two small oval areas of bright iridescence on a tiny blue juvenile fish. It is not uncommon to see schools of skipjack tuna feeding aggressively on these larval and post-larval kahawai when they are abundant. The bars that are on the post-larval kahawai’s back soon fade and break up as the fish grows. They develop into the characteristic black, brown, and yellow spots of the young kahawai. This has been observed by catching post-larval kahawai in dip nets and on-growing them in aquaria.”* (Craig Worthington, Marine Aquarium Collector, extract from an interview documented in Hartill & Walsh 2005).

Nursery habitats

Juvenile 0+ kahawai greater than 35 mm were often caught during a nation-wide estuarine beach seine survey conducted between 2001 and 2006 (M. Morrison & M. Francis, NIWA, unpubl. data) and their abundance was considered to be relatively low but widespread (Francis et al. 2005, 2011). Kahawai encounter probabilities were higher in estuaries with clear sandy substrates, and it is possible that juveniles are also found in sheltered sandy embayments on the open coast (M. Francis, NIWA, pers comm.). In Australia, juvenile kahawai are often found in close association with eelgrass (*Zostera* spp.) meadows (Robertson 1982). This pattern is not evident in New Zealand estuaries, with an exception being small kahawai associated with inter-tidal seagrass meadows in the Kaipara Harbour (M. Morrison, unpubl. data), for reasons that are not readily apparent. Juvenile fish (0+ and 1+) have been caught off central Bay of Plenty beaches in the general ‘surf zone’ (M. Morrison, pers. obs.), suggesting that alternative juvenile habitats to those found in estuaries are also used in some regions.

As they grow past fifty millimetres the young wild kahawai appear to take up residence in very shallow water along beaches. They can also be found in abundance around coastal estuaries. As they grow further they seem to move up the estuaries and spend much of their juvenile years in an upper harbour environment. Other strong nursery areas are found where river mouths and estuaries empty

out through surf beaches” (Craig Worthington, Marine Aquarium Collector, extract from an interview documented in Hartill & Walsh 2005, follows directly from text in preceding section above).

The feasibility of obtaining recruitment (0+ cohort) indices from beach seine samples was tested between November 1996 and September 1997 in the Manukau, Waitemata, and Tauranga Harbours, and in Golden Bay. Catch rates were highly variable, both between sites and between months within sites (Gerring & Bradford 1998) and this sampling approach has been abandoned because of this variability. The best available information on temporal recruitment trends comes from recreational catch sampling, which suggests that recruitment to the adult population on the north-eastern coast of the North Island has been broadly steady since 2001 (Armiger et al. 2006).

Adult habitats

Sexually mature kahawai are predominantly pelagic, forming schools of similar sized fish, although solitary adults have been observed as far as 50–60 km up the Waikato River (Sherrin 1886) and have been caught offshore in waters as deep as 200 m. There is good evidence to suggest that the behaviour and residency of adult kahawai can vary considerably in different parts of the country.

Adult (and immature) kahawai are commonly found in estuaries, river mouths and shallow coastal waters in moderate sized schools ranging from 1–10 t. In the Firth of Thames, commercial set net fishers have suggested that these small schools are resident in bays over many years, and some fishers serially crop several schools during a season, and monitor their recovery over the following years before fishing them again (Daniel Scott, commercial set net fisher, pers. comm.). These schools are found in shallow water at night, but may move out further off the shore and into nearby deeper waters during daylight hours.

“Like most other ring netters in the Gulf I fish for kahawai almost exclusively at night. Ring netters mainly target schools of kahawai that have moved from occupying deeper water during the day to sandy and pebbly shallow embayments at night. The depth of water the kahawai occupy at night can be from as little as 6 inches to 2 feet deep, and can range up to 20 feet deep. This is mainly over the winter period (June–July). The kahawai are not feeding at night, just resting in relatively tight schools of usually between 1–3 tonnes. These are the size of schools I mainly target, although I have witnessed aggregations of up to 1–2 km of fish in shallow water along a coastline. The fish are observable because of the phosphorescence in the water, so a night with no moon is best. The phosphorescence shows up when each fish within a school moves about. This is how we find them, and I can usually tell the rough size of the fish (when we get closer to the school) within the schools using the outline of the phosphorescence as an individual fish swims about.” (Brendan Taylor, commercial set net fisher, extract from an interview documented in Hartill & Walsh 2005).

Larger schools of up to 300 t are found on the open coast, but these appear to be more mobile. Kahawai in these schools are often associated with similar sized jack mackerel (*Trachurus* spp), blue mackerel (*S. australasicus*), or trevally (*Pseudocaranx dentex*) (Taylor 1999b). Aerial sightings data provided by the fishing industry are the best source of information on the distribution of larger adults in open waters, as kahawai are only really vulnerable to trawl based methods during the spawning season when they are found closer to the sea floor. The geographical distribution of surface schooling kahawai is displayed as plots of aerial sightings, both for monospecific and mixed schools of fish, in Taylor (1999b) and Bagley et al. (2000). Most large schools of adult kahawai have been observed on the open coast, nearby offshore islands and associated reefs.

Adult migrations and movements

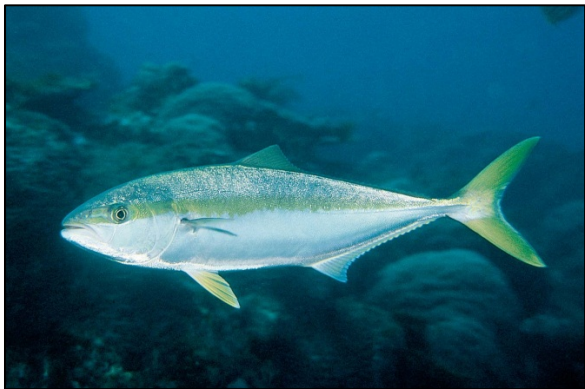
The only empirical source of information on movement is that obtained from two large scale tagging programmes. Between October 1981 and February 1984, 13911 kahawai were tagged throughout New Zealand waters, of which 1190 recaptures were reported (Wood et al. 1990). Of those reported with a known recapture location, 50% had moved less than 40 n. miles, 95% less than 265 n. miles, and 99% less than 500 n. miles, with the greatest movement being 743 nautical miles in less than a year. A second tagging programme took place in the Bay of Plenty and Tasman Bay in 1991, in which 9606 kahawai were tagged and released (Griggs et al. 1998). Of these, 1492 tags were returned, with 50% moving less than 8 n. miles, 95% less than 55 n. miles, and 99% less than 250 n. miles, with the greatest movement being 450 nautical miles in less than four years. Regardless of the distance travelled, almost all movement took place within Quota Management Areas (QMAs; which are partially based on geographical features relating to known stock boundaries for other species such as snapper). Some kahawai were therefore recaptured hundreds of miles from their point of release, but the majority appear to have been comparatively resident. Recreational landings sampled on the north-eastern coast of the North Island since 1990 suggest that there are distinct and consistent differences in population composition over smaller spatial scales (B. Hartill, unpubl. data).

Comparisons are often made between migratory patterns exhibited by Australian salmon (kahawai) and kahawai in New Zealand. There are two species of Australian salmon, eastern (*Arripis trutta*), which is that found in New Zealand and western (*A. truttaceus*). These species have only recently been distinguished as separate species, which co-occur, but undergo markedly different migratory behaviour. In Australia, *A. trutta* migrate to a 300 km stretch of coast between Lakes Entrance and Bermagui, to spawn. For fish from Tasmanian waters this means a movement of up to 600 km to the mainland, as spawning does not appear to take place locally. *A. truttaceus* also migrate to spawn, but the distances are thought to be much greater, in the order of thousands of kilometres, to spawning grounds in southern Western Australia. The magnitude of movements by *A. trutta* in Australia are, therefore, more similar to those of their New Zealand co-specifics than those of *A. truttaceus*, but are still greater than suggested for kahawai in New Zealand through tagging data.

Population connectivity

Smith et al. (2008) assessed the feasibility of using otolith microchemistry and stable isotope signatures in otoliths to determine kahawai stock structure in New Zealand. A statistical comparison of chemical signatures of otoliths taken from juveniles collected at Okahu Bay (Waitemata Harbour) and Hakahaka Bay (Port Underwood) failed to detect any significant differences. The researchers concluded that the results were inconclusive, and suggested that the methods used lacked sufficient resolution to give meaningful results.

3.20 Kingfish (*Seriola lalandii*)

<p>Fisheries catch: Commercial: 171 t¹ Recreational: 500–700 t, in KIN 1^{1*}</p> <p>Sexual maturity: 8–10 years / 83 cm males, 97 cm for females^{1,2}</p> <p>Maximum age: 20 years / 150 cm^{2,3}</p> <p>Pelagic phase duration: Eggs: Unknown Larvae: Unknown</p>	 <p>Photo credit: M. Francis, NIWA</p>
<p>¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 2, 2012; *Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²McKenzie et al. (2014); ³Francis (2001).</p>	

Kingfish are widely distributed around the North Island and the northern half of the South Island, generally in depths of less than 150 m. This species is widespread in the Atlantic and Pacific Oceans (Nugroho et al. 2001). In Australia its distribution extends from North Island in Queensland, across the eastern and southern coastlines, including the east coast of Tasmania, Lord Howe Island and Norfolk Island, to Trigg Island in Western Australia (Love & Langenkamp 2003). In New Zealand, *S. lalandii* occurs from the Kermadec Islands (29°S) to Foveaux Strait (46°S) (Walsh et al. 2003).

Spawning

Anecdotal evidence suggests that kingfish spawn across a range of settings, from estuaries out to deep water (C. Poortenaar pers. comm in Hurst et al. 2000a, Walsh et al. 2003). Running ripe fish have been reported on Ranfurly Bank (off East Cape) in mid-January (McGregor 1995). Monitoring of GSI of wild fish from 1998 to 2000 returned the highest values from November to January, indicating that they were spring-summer spawners (Poortenaar et al. 2000); kingfish in Australia also appear to spawn at this time (Gillanders et al. 1997). Poortenaar et al. (2000) found 50% of females mature at 94 cm and 50% of males at 81 cm. This differed from the mature size range of 58–67 cm reported by McGregor (1995), but Poortenaar et al. (2000) was not able to account for this difference as "mature" was not defined by McGregor (1995). An observation of spawning in a related kingfish species off California (*S. lalandii dorsalis*) found hundreds of fish milling about making short circles near the surface. This behaviour was observed from 11:00–16:00 hours, with the water appearing white from copious amounts of sperm and eggs (Baxter 1960). Observations of spawning in captive kingfish (*S. durneri*, *S. quinqueradiata*, *S. lalandii aureovittata*) show that males chase females from the bottom of the tanks, with spawning occurring at the surface (Tachihara et al. 1993, Keitaro Kato, pers. comm. in Walsh et al. 2003).

Egg and larval transport

No information is available.

Nursery habitats

Juvenile kingfish and their habitats are very poorly known in New Zealand. Individuals have been caught around the Poor Knights Islands, and in lights traps in waters adjacent to the Leigh Marine

Laboratory, in the outer north-western Hauraki Gulf (6 fish, about 58 mm TL, Leigh Marine Laboratory, unpubl. data, in Walsh et al. 2003). Very small kingfish have been caught in the outer Hauraki Gulf in late January, and juveniles can be found well offshore under drift algae and other floating debris (McGregor 1995).

In Japan, juvenile *Seriola* spp. are collected for the aquaculture industry when they are associated with drifting seaweed (Sakakura & Tsukamoto 1997). *S. quinqueradiata* is the dominant species, with *S. lalandi aureovittata* juveniles being less common (Keitaro Kato, pers. comm., in Walsh et al. 2003). Work on *S. quinqueradiata* has found social hierarchies to exist within groups of fish of the same general age, with cannibalistic behaviour being common from 22 to 36 days post hatching (Sakakura & Tsukamoto 1996, 1997).

A two year study of fish aggregation devices (FADs; in this case 1 m surface floats with mooring lines, in about 100 m water depth) at an inshore (3 km off coast) and offshore site (10 km off coast) on the continental coast off Sydney, Australia, found kingfish to be present all year round, with the most sightings being seen in summer (visual counts) (Dempster 2004). Fish were seen more often at the inshore site in summer, autumn counts were equivalent, and winter and spring counts found fish to occur more frequently at the offshore FADS (though none of these patterns were statistically significant). Of 2119 kingfish observed over three years, less than 2% were larger than 600 mm FL (keeping in mind that the same fish may have been counted across multiple sampling events, n=81). Average size of fish within any given school ranged from 60 to 550 mm FL, and most fish (about 75%) were in the 300–500 mm FL band. Schools of small fish (180–260 mm FL) were particularly common in October and December, while the greatest attraction to FADs occurred in summer, with most fish being 300–400 mm FL (less than 1 year old, Gillanders et al. 1999a, b), and large schools of 100–500 fish being seen in summer and autumn.

Adult habitats

In New Zealand kingfish are mainly found off the northern half of the North Island, but have a wider overall range extending from the Kermadec Islands down to Foveaux Strait (Francis 2001), to water depths of 200 m. As a semi-pelagic species they occur mainly in open coastal waters, especially in association with rocky outcrops, reefs and pinnacles, but are also observed over soft sediment seafloors, and within shallow enclosed bays and estuaries (Walsh et al. 2003).

Heagney et al. (2007) used a mid-water baited remote underwater video (BRUV) at Lord Howe Island Marine Park, off eastern Australia (31.5°S, 159.1°E) to survey pelagic and mid-water fish assemblages. Current speed had the greatest effect on pelagic assemblages (other variables measured were depth and temperature): *Seriola rivoliana* (amberjack) and *Scomber australasicus* (blue mackerel) had similar distributions and were associated with low flow environments; while *S. lalandi* was associated with the higher flow environments sampled, after corrections for bait plume dispersal (NB: though current speeds in the sample area were relatively slow: mean 0.17 m s⁻¹, range 0.03 to 0.34 m s⁻¹, and a total of 79 *S. lalandii* were detected, including two schools of n=30 and n=34 respectively).

Hobday & Campbell (2009) looked at the associations of mobile fish species with nearshore topographic structures (all in 60–70 m water depth), including *S. lalandii*. Eight hundred and ninety hours of trolling were completed over 102 days, over a seven year period in southern Western Australia, both over and away from topographic features on the continental shelf. Eighty percent of all kingfish captured (n=271, across 49 days, 42–138 cm FL) were within 1 km of one of the eight topographic features included, with catch rates being 26 times higher than those areas away from

these features. The mean distance from the centre of each feature was 303 metres (range 125–465 m), with the water depth ranging from 2 to almost 40 m. There was no relationship between kingfish CPUE and sea surface temperature, suggesting that these fish were resident all year round; however there were CPUE differences between different years at topographic features that remained unexplained.

Adult migrations and movements

Holdsworth & Saul (2004) reported on kingfish tag-recaptures in New Zealand waters, with half of fish less than 850 mm being captured within 5 n.miles of their release point, while 31% moved more than 15 n.miles. Larger kingfish (1050–1500 mm) moved less, with 77% moving less than 5 n.miles, and only 13% more than 15 n.miles. White Island fish exhibited a different pattern, with 96% of fish recaptured in the same area. Notable longer distance movements included: a 9 kg fish tagged off Tolaga Bay (April 2002) recaptured 252 days later (December 2002), 253 n.miles to the south near Ngawi, South Wairarapa Coast; a 11.7 kg fish tagged on Ranfurly Bank (February 2002) recaptured 13 months later, 410 n.miles to the south-west at Cable Bay, north of Nelson; and a 20 kg fish tagged at the Three Kings Islands (May 2002) recaptured 97 days later, 214 n.miles south-east at the southern end of Great Barrier Island, Hauraki Gulf.

Holdsworth & Saul (2011) reported further on this long term tagging programme, and found that in 2010–11 over 70% of recaptures were within 5 n.miles of where they were tagged. The largest distance moved was in that year was of a fish tagged in Pegasus Bay, east coast of the South Island, recaptured 220 n.miles to the north-west, off Cape Egmont. Two contrasting movement examples given were a 900 mm fish tagged off Raglan and caught 20 days later 60 n.miles to the north off Murawai Beach; and a small kingfish (no size given) tagged off Christchurch (February 2008) and recaptured 960 days later, 220 n.miles to the north-west in the South Taranaki Bight in a trawl net. The authors noted that there were fewer than 10 out of 1300 kingfish tag recoveries where kingfish were known to have moved from the east coast to the west coast, or vice versa. Across the overall time scale of the tagging programme, three fish also crossed the Tasman Sea to Australia, as well as recaptures from Lord Howe Island and Wanganella Banks (well to the north-west of the Three Kings Islands).

Gillanders et al. (2001) used tag-recaptures from a cooperative tagging programme to look at movement patterns of kingfish along the New South Wales coast, Australia (17190 fish tagged between 1974–95, size range 200–1200 mm, 8% effective return rate). Small fish (under 600 mm) moved less than larger fish (over 750 mm), although few fish larger than 1000 mm TL were tagged. However, one fish of 310 mm TL moved 678 km. Most fish were recaptured within 50 km of where they were tagged, with some indication that fish at large longer moved greater distances. The maximum distance moved was 3000 km, and the maximum time at liberty 1742 days. Three fish moved to New Zealand (over 2000 km), while seven other fish moved more than 500 km, including one fish to Lord Howe Island, and another to Queensland.

A smaller tagging programme on kingfish in Spencer Gulf, South Australia (241 fish released, 24 recaptured (10%)), found larger fish to remain in (or return to) northern Spencer Gulf, and it was suggested that this region might be important for aggregations of large, reproductively mature fish (Hutson et al. 2007a). The maximum distance moved was 130 km, and the maximum time at liberty 442 days.

Patterson & Swearer (2008) looked at the otolith chemistry of juvenile kingfish from around Lord Howe Island, as well as several NSW sites and a nearby oceanic reef system (Elizabeth and

Middleton). The elemental signatures separated out strongly by site. The application of these signatures to adult fish (juvenile portion of otolith) from Lord Howe Island suggested that 28% of the adult fish sampled may have locally originated or from the nearby oceanic reef system; with the majority of fish probably being sourced from mainland spawning grounds (currently unknown). It was concluded that at least some fish spawned locally with subsequent larval retention, creating a resident population, augmented by adult migration and larval dispersal from other locations.

Population connectivity

Although kingfish are capable of moving very large distances, indications from tagging are that most adult kingfish stay within localised areas in New Zealand (Walsh et al. 2003, Holdsworth & Saul 2004, 2011). This is likely to make them more vulnerable to local depletion (Walsh et al. 2003). Miller et al. (2011) looked at the genetics of kingfish across temperate Australia (NSW, Victoria, SA and WA) and New Zealand using seven polymorphic microsatellite loci, as well as a mitochondrial gene. Western Australia fish were genetically distinct from the other regions sampled. No difference was found between New Zealand fish, and eastern (NSW) or central (SA, Victoria) Australian fish. This agreed with earlier work that found no evidence of genetic differentiation between New Zealand and New South Wales fish (Nugroho et al. 2001), and another study that found similarities between *S. lalandii* ectoparasite assemblages in eastern Australia and New Zealand (Hutson et al. 2007a). Miller et al. (2011) suggested that the eastward flowing Tasman Front could contribute to mixing between the two regions; with recent migration rates (genetically speaking) supporting this with a larger migration from NSW to New Zealand than vice versa.

3.21 Leatherjacket (*Parika scaber*)

Fisheries catch:

Commercial: 573 t¹

Recreational: Negligible¹

Sexual maturity: 2 years / 19–22 cm²

Maximum age: at least 7 years / 30 cm²

Pelagic phase duration:

Eggs: Unknown

Larvae: 22–66 days (dependent on wind climate)³



¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 2, 2012; ²Francis (2000); ³Kingsford & Milicich (1987).

Leatherjacket (smooth leatherjacket, *P. scaber* – also valid as *Meuschenia scaber*) occurs in temperate Australian waters, from Western Australia to New South Wales and Tasmania, as well as in New Zealand. They have also been recorded at Lord Howe and Kermadec Islands (Francis 1993a). In New Zealand they are found around most of the country, especially in association with rocky reef habitats, but are more common in the north. Although not a schooling species, leatherjackets may be found in small groups (MPI 2012). Leatherjackets are omnivores and feed on sessile encrusting organisms such as sponges and ascidians (Russell 1983). Poynter (1980) noted that small leatherjackets feed on amphipods in the macroalgal canopy. Jones (1988) commented that adult fish are known to switch between benthic feeding and open water feeding at irregular intervals.

Spawning

Leatherjackets spawn around nest sites prepared and guarded by the male of the species in spring and summer (FishBase 2012). Males often form pairs with females over the spawning season, and the

females become confined to the male's territory for this period (Thompson 1981). Leatherjackets hatch from demersal eggs (Milicich 1986). Ripe gonads have been recorded between August and November from fish within the Leigh Marine Reserve (Thompson 1981).

Egg and larval transport

Once the leatherjacket's demersal eggs hatch from their nests, they become pelagic larvae. Dudley et al. (2000) investigated the swimming ability of several pelagic, late larval stage New Zealand reef fish including the leatherjacket, in an attempt to investigate whether these juvenile fish acted as passive particles, or were active swimmers capable of covering large distances under their own power. Leatherjacket larvae were able to swim in current chambers for an average distance of 50 km, suggesting that they are potentially capable of active movement towards suitable habitats at relatively large scales. However, Kingsford & Choat (1985) identified that large numbers of pre-settlement leatherjackets are associated with drift algae at both inshore and offshore localities; and is not clear whether and/or when active swimming strategies might be deployed.

Nursery habitats

Poynter (1980) identified that juvenile leatherjackets recruit into the heads of *Ecklonia radiata* plants, which form algal forests on rocky reef habitats. It appears that the kelp heads are the principal settlement and initial growth habitats for this species, with new recruits appearing at 8 to 12 mm TL in these rocky reef habitats (Kingsford & Milicich 1987).

Adult habitats

This species is widespread over the inner shelf and is commonly found at depths of 40–60 m, but may occur to depths of 100+ m (Anderson et al. 1998, Francis et al. 2002). Recent fine scale habitat association work in northern Victoria, Australia, has found leatherjacket to be more common in heterogeneous reef landscapes offering clusters of small interconnected patches of reef with a lot of edge environment (Moore et al. 2011), as opposed to more homogeneous reef areas.


Adult migrations and movements

No information is available.

Population connectivity / stock structure

No information is available.

3.22 Lemon sole (*Pelotretis flavilatus*)

<p>Fisheries catch: Commercial: 2467 t¹* Recreational: <30 t</p> <p>Sexual maturity: 2 years²</p> <p>Maximum age: 6–7 years / 50 cm³</p> <p>Pelagic phase duration: Eggs: 95 hours (4 days)⁴ Larvae: Unknown</p>	 <p>© NIWA M. Francis</p>
<p>¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012. *Landings for eight combined species of flat fish; ²Rapson (1946); ³Stevens et al (2004); ⁴Robertson & Raj (1971).</p>	

Lemon sole is a demersal flatfish species belonging to a group known as right-eyed flounders, and are found around New Zealand, including Stewart Island and shallower parts of the Chatham Rise and

Egg and larval transport

Little is known about egg or larval transport for this species. In the Hauraki Gulf, peak larval abundance was recorded between April and July (Roper 1986).

Nursery habitats

Roper & Jillett (1981) identified lemon sole in catch from otter-trawl surveys in Blueskin Bay, Dunedin. The authors identified a strong depth versus size relationship, with smaller lemon sole occurring in shallower inshore areas (15 m water depth) and larger individuals occurring in deeper waters (30 m water depth). No lemon sole were found in the shallower waters of the surrounding inlets. More recent extensive surveys of estuaries through New Zealand, including Blueskin Estuary, show that lemon sole are not found as juveniles in estuarine habitats (Francis et al. 2005, 2011).

Adult habitats

An analysis of trawl survey data from the Hauraki Gulf by Kendrick & Francis (2002) identified lemon sole as part of a fish assemblage correlated with sand and deep mud (>50 m water depth) sites. A study of demersal fish assemblages on the continental shelf and upper slope off the east coast of the South Island (Pegasus Bay and the Canterbury Bight) by Beentjes et al. (2002) identified that most of the flatfish catch was a combination of lemon sole and New Zealand sole (*Peltorhamphus novaezeelandiae*) mixed together.

Adult migrations and movements

Nothing is known about fish movements, aside from Rapson's (1946) suggestion that fish made large distance spawning migrations. He also commented that lemon sole were present in water more than 30 fathoms deep (about 60 m), and "*it is believed for part of the year they make extensive migrations to deep water and consequently avoid the extremes of temperature in more shallow water*".

Population connectivity

No information is available.

3.22 Ling (*Genypterus blacodes*)

Fisheries catch:

Commercial: 12337 t¹

Recreational: 15–40 t^{1*}

Sexual maturity: 6–11 years / 65–100 cm²

Maximum age: 30 years / 170 cm^{1 & 2}

Pelagic phase duration:

Eggs: Unknown

Larvae: Unknown

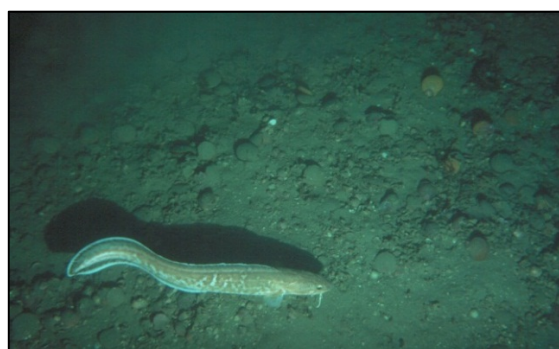


Photo credit: Wilan

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 2, 2012; ^{*}Represents an estimate for LIN 1 only. In the 1996 national diary survey for LIN 1, 5, and 7, numbers were too low to provide reliable estimates; ²Horn (2005).

New Zealand ling is a bathydemersal species of cusk-eel (not a true eel) found in the waters around New Zealand, southern Australia and Tasmania, Chile and Brazil (González-Olivares et al. 2009). Ling have been recorded from trawl surveys around New Zealand including on the Challenger Plateau, the Chatham Rise and in the Sub Antarctic (Hurst et al. 2000a). They live in water depths ranging between 200 and 800 m, but are more commonly found in depths between 300 and 550 m

(Kailola et al. 1993). Ling are predominantly benthic feeders and feed mainly on natant decapods, macrourid fishes and small hoki (and are often caught feeding on hoki, during the hoki spawning season; Clark 1985, FishBase 2012). In general, ecological knowledge of this species is fragmentary at best, due to a lack of basic biological and fishery information (Wiff et al. 2007). Mitchell (1984) sampled the diet of ling from around New Zealand, and found a dominance of fish, crustaceans, molluscs, polychaete, and bryozoans, concluding that they had an exclusively benthic feeding mode. Small ling (30–80 cm) preyed largely on crustaceans, whereas large ling (80–160 cm) preyed on fish. More recent work on the Chatham rise by Horn & Dunn (2010) found similar trends.

Spawning

Ling have external fertilisation and spawn oval eggs which float in a gelatinous mass in pelagic waters (Breder & Rosen 1966). Spawning is known to occur off the west coast of the South Island, Puysegur Bank (Patchell & McKoy 1985, Colman 1988), the east coast of the South Island and the Chatham Rise (Horn 1993b), Cook Strait and the Campbell Plateau (Horn & Ballara 1999). Some data suggests ling are winter spawners from August to October (Graham 1939b, Paul 2000), while other data suggests they spawn in early spring/summer (Annala et al. 1999). Australian researchers have found a spawning season from May to October (Kailola et al. 1993). Roberts (1997) recorded a ‘pre-spawning’ aggregation of ling off Northland, but it was not known if those fish remained in the area to spawn.

Egg and larval transport

No information could be found, aside from Parsons (1999) sampling a few larvae in the inner shelf waters off Dunedin in December.

Nursery habitats

Little is known about juvenile ling distributions below 40 cm, with juveniles appearing in trawl survey data at about 40 cm TL (Annala et al. 1999). Two year old fish (mean length 34.9 cm) have been sampled from the Chatham Rise and Southern Plateau (Horn 1993b). Hurst et al. (2000a) reported that 0+ juveniles have been recorded from shallow inshore areas, but most occur from 200–500 m water depth, with the main areas including the Bay of Plenty, and central east coasts of the North and South Islands. A few have been recorded from the west coast South Island, Chatham Rise, Southland and the Auckland Islands. However, Hurst et al. (2000a) also noted that larger cod-end mesh sizes (60 mm or greater) were used in the areas where they were less common, and may have caused size selectivity bias. There was also very little sampling around the North Island. Juvenile ling were sampled during *Kaharoa* trawl surveys off the Bay of Plenty (in 18 tows), off the south-east coast of the North Island (in 167 tows) and off the east and west coast of the South Island (in 742 tows). Catch rates were relatively patchy; the largest North Island catch (0.1 t.km⁻²) was east of Cook Strait and the largest South Island catch rates (up to 1.5 t.km⁻²) were on the shelf in Canterbury Bight. Juvenile ling have also been recorded on *Tangaroa* middle depth trawl surveys mainly on the Chatham Rise, and off Southland (925 tows total). Catches were widespread on the Chatham Rise, although one large catch (0.7 t.km⁻²) dominated the distribution. Off Southland, catches were restricted to the south-eastern shelf edge and around Puysegur Bank, unlike the larger fish which were more widespread across the shelf (Hurst et al. 2000a).

Adult habitats

Adult ling are widely dispersed over the New Zealand region, especially south of 40°C, in 200–700 m depth (Annala et al. 1999). Trawl survey data has identified that ling are very common along the outer shelf of the east coast of the South Island, and more so in summer compared to winter (Beentjes et al. 2002). Ling were also found to be common along the northeastern and eastern sides of the Chatham

Rise (Doonan et al. 2009). Ling have been observed occupying burrows in mud in shallow water off Stewart Island (Mitchell 1984).

Adult migrations and movements

Little is known for New Zealand. Horn (2005) inferred large scale migrations for spawning, based on the presence of relatively discrete spawning grounds in different regions (see next section).

Population connectivity / stock structure

Horn (2005) examined possible ling stock structure in New Zealand, using a range of data sources including genetics and morphology work, fisheries catch, and life history characteristics. It was concluded that life history data provided the strongest evidence of multiple ling stocks, including significant differences in growth parameters between all the five assessed fisheries 'stocks' (Campbell, Chatham, Bounty, WCSI, and Cook Strait). There were relatively distinct spawning grounds in all these areas, and some marked differences in the timing of spawning between some areas. Differences in age and length at 50% maturity were also apparent. Horn (2005) also noted that there might be further sub-divisions at finer scales, with for instance two relatively distinct spawning areas on the Chatham Rise (one west of the Chatham Islands, the other east of Mernoo Bank) and significant differences in growth parameters between sub-areas of the Chatham Rise. The Campbell area also held two relatively distinct spawning grounds; the area from Puysegur Bank to the Solander Corridor, and the area from the southeastern Snares shelf to the Auckland Islands. It was considered likely that the Campbell area was home to a single ling stock, based on information from trawl survey series conducted in summer and autumn (O'Driscoll & Bagley 2001). During the summer, when ling were spawning, catch rates were high in the two spawning areas and relatively low on the eastern Campbell Plateau. In autumn, some months after spawning had finished, catch rates were relatively constant over all of the survey area. This was indicative of a single stock, with spawning fish tending to move northwest to the spawning grounds, and later disperse over the whole area outside the spawning season. The differences in the maturity from the Puysegur and Campbell areas were also best explained by there being a single biological stock in the Campbell-Puysegur area (Horn 2005).

3.23 New Zealand sole (*Peltorhampus novaezeelandiae*)

Fisheries catch:

Commercial: 2467 t¹*

Recreational: Unknown

Sexual maturity: Unknown

Maximum age: Unknown

Pelagic phase duration:

Eggs: Unknown

Larvae: Unknown



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¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; *Landings for eight combined species of flat fish. Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around use of these data

New Zealand sole have been caught in research trawls mainly around the northern North Island and east and west coasts of the South Island, including Tasman Bay, mainly in less than 50 m depth (Stevenson 2004).

Spawning

No information is available.

Egg and larval transport

Eggs of this species have been recorded from Pauatahanui Inlet (Healy 1980) and off the Otago coast from autumn to spring (Robertson 1973, Parsons 1999).

Nursery habitats

Juveniles have been caught by trawlers in all areas where the species has been recorded. They occur close inshore in less than 75 m depth (Hurst et al. 1998). Only occasional individuals are found inside estuaries and harbours (Francis et al. 2011) and it is suspected that early accounts of juveniles in estuaries may have been a result of confusion with juveniles of the speckled sole *Peltorhamphus latus*, which are very abundant in estuaries.

Adult habitats

No information is available.

Adult migrations and movements

No information is available.

Population connectivity / stock structure

No information is available.

3.24 Red cod (*Pseudophycis bachus*)

Fisheries catch:

Commercial: 6691 t¹

Recreational: 205–388 t^{1*}

Sexual maturity: 2–3 years / 45–55 cm¹

Maximum age: 6 years /
70 cm²

Pelagic phase duration:

Eggs: Unknown

Larvae: Unknown



¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 2, 2012; *Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²Horn (1996).

Red cod belong to the morid cod family and are found in waters around southern Australia (from Sydney to Adelaide and Tasmania) and New Zealand. Red cod are a fast-growing and short lived demersal fish species (Stevenson 2004). Their distribution around New Zealand is fairly universal, including the Chatham Rise and the Sub-Antarctic Islands, but they are more predominant to the south of this range (Habib 1975). Red cod have been caught in research and commercial trawls all around New Zealand, across the Chatham Rise and in shallower areas of the Sub-Antarctic, from 26 m down to about 500–700 m depth (Anderson et al. 1998, Stevenson 2004), but most commonly in 200–300 m water depth along the edge of the continental shelf (Armitage et al. 1994). Red cod are primarily bottom feeding omnivores and feed on fishes, cephalopods, crabs and other crustaceans (Habib 1975). Beentjes & Renwick (2001) found that recruitment of red cod into the commercial fishery was related

to the sea temperature and weather conditions which prevailed during the early life history period, particularly for 1+ juvenile's (i.e., lower sea temperatures produce higher recruitment success).

Spawning

In general, morid cod species eggs are pelagic, buoyant and usually small. In New Zealand red cod are hypothesised to spawn in deep waters (Graham 1956, Habib 1975) probably along the length of the continental slope (Beentjes & Renwick 2001). Off Otago, fish in ripe condition were observed to leave harbour and inshore areas of Otago for the deeper waters of the North Reef (Graham 1939b). Red cod from the Canterbury Bight spawn from August to October, although fish that appeared to be in maturing condition have been recorded in January. A later spawning period has been suggested for higher latitudes (Beentjes & Renwick 2001). On Puysegur Bank, running ripe fish were caught in 600 m in February 1994 (Annala et al. 1999). Hurst et al. (2000a) examined all available trawl survey gonad staging data, and concluded that the data suggested little spawning activity around the North Island, spawning activity around the South Island occurring mainly in late winter/early spring, but with a secondary peak in autumn, and that spawning in the Sub-Antarctic might be slightly later in spring/summer.

Egg and larval transport

In general, very little is known about the early life history of red cod (Beentjes & Renwick 2001). The egg/larval phase of northern hemisphere morid species is approximately six weeks, but is not known for New Zealand (Habib 1975). A few larvae have been sampled in the inner shelf waters off Otago (Parsons 1999). However, in general plankton studies have failed to find red cod eggs or larvae over the continental shelf, and it is likely that these stages exist in deeper water (Beentjes 1992).

Nursery habitats

Shuntov (cited in Habib 1975) identified that juvenile red cod can be found in waters off the continental shelf after summer spawning, in depths ranging from 300 to 750 m. There are no known red cod nursery grounds although juveniles have been caught in deep water after the spawning period. Graham (1939a) did find juveniles in Otago Harbour, but they were not sampled there or in any other estuaries as part of a series of national small estuarine fish surveys (Francis et al. 2005). Young (0+) juveniles have been caught in trawl surveys around the mainland, although relatively infrequently around North Cape, the South Taranaki Bight, and off Southland. The depth of capture is mostly less than 250 m, but extends down to about 450 m (Hurst et al. 2000a). Juveniles up to 2 years old have a similar distribution, although they are also commonly caught on the Chatham Rise, off Southland and around the Auckland Islands, with a higher proportion being caught in deeper water (200–450 m) than for 0+ juveniles. *Kaharoa* trawl surveys show them to occur from inshore to the shelf edge, being most abundant in the South Canterbury Bight (maximum catch of 21.8 t.km⁻²). On the south-west coast of the North Island, larger catch rates were patchy, ranging up to 2.4 t.km⁻². Juvenile red cod have also been recorded on *Tangaroa* middle depth trawl surveys on the Chatham Rise and off Southland and in *Akebono Maru* 73 tows around the Chatham Islands. Juveniles occurred in the shallowest depths sampled across the Chatham Rise (mainly 200–300 m), to the east of the Mernoo Bank, and west of the Chatham Islands. At the Chatham Islands, juveniles were rarely caught by *Akebono Maru* 73 and catch rates peaked at 0.5 t.km⁻¹. Off Southland, juveniles were occasionally caught, mainly in mid to outer shelf depths, and the largest *Tangaroa* catch rate (12.1 t.km⁻²) occurred on the southern edge of the shelf (Hurst et al. 2000a).

Adult habitats

Adults are abundant along the east coast of the South Island (Beentjes et al. 2002); however Doonan et al. (2009) found them to be rare along the northern and eastern slopes of the Chatham Rise.

Adult migrations and movements

No information is available.

Population connectivity / stock structure

No information is available.

3.25 Red gurnard (*Chelidonichthys kumu*)

Fisheries catch:

Commercial: 3289 t¹

Recreational: 300–500 t^{1*}

Sexual maturity: 2–3 years / 23 cm^{1,2}

Maximum age: 16 years / 55 cm¹

Pelagic phase duration:

Eggs: Unknown

Larva: 8 days³

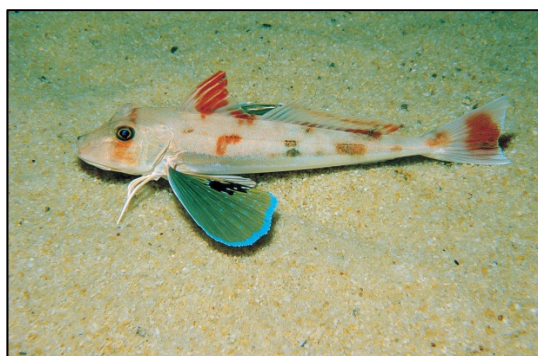


Photo credit: M. Francis, NIWA

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ^{*}Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²Elder (1976); ³Roberston (1980b).

Red gurnard are found in Australia (as far north as southern Queensland on the east coast and Shark Bay on the western coast), South Africa and Mozambique, and New Zealand. In New Zealand, they are widely distributed from Cape Reinga to Stewart Island, including the shallower regions of Chatham Rise and the Chatham Islands, from 10 m to 200 m water depth (McMillan et al. 2011). Although few trawl records exist from the south west coast of the South Island, its range also extends into Fiordland (Francis & Ling 1985).

Spawning

Based on research trawl and commercial observer data, Hurst et al. (2000a) reported ripe, running ripe and spent fish being caught around most of New Zealand (with the exception of the Hauraki Gulf) throughout the year. Peak numbers (i.e. more than 40% of all three stages combined) were found between December and February in all areas except for the west coast of the South Island and Tasman Bay where March and April were shown to be the peak times. However, although spawning red gurnard have not been recorded in trawl or fishing observer records in the Hauraki Gulf (possibly due to the timing of collections) they are seasonally present. Elder (1976) found mature and spawning males and females in Craddock Channel (between Little and Great Barrier Island) all year round, with the pattern in catch rates of spawning females both there and in the inner gulf suggesting a seasonal migration offshore (of females in particular) in the spring and summer months. This migration was likely to be related to water temperature, with a corresponding post-spawning migration of spent fish occurring in the reverse direction. More recent studies of the hormonal activity and gonadosomatic (GSI) and hepatosomatic (HSI) indices of red gurnard sampled from commercial long line catches in the Hauraki Gulf indicated a spawning period beginning in September, peaking in November/December, and continuing at a lower level until May (Clearwater & Pankhurst 1994).

Egg and larval transport

Crossland (1982) collected red gurnard eggs during both December and January-February sampling cruises in the Hauraki Gulf (Figure 12). They were never abundant and mainly occurred west of

Elder's proposed spawning area in Craddock Channel, between Bream Head and Little Barrier Island. Eggs and larvae were also recorded in east Northland in October and December, with concentrations in the Bay of Islands and Great Exhibition Bay. Elsewhere, eggs have been occasionally recorded in coastal waters including Otago, Kaikoura, Castle Point, Bay of Islands, and Milford Sound (Graham 1956, Robertson 1973, 1975, 1980b, Parsons 1999, Hickford 2000). Egg and larval development is pelagic with 8 days' drift before feeding begins (Robertson 1980b). Hickford's study of fish larvae in the Kaikoura region found low numbers of red gurnard larvae ($n=10$), with a mean size of 8.8 mm.

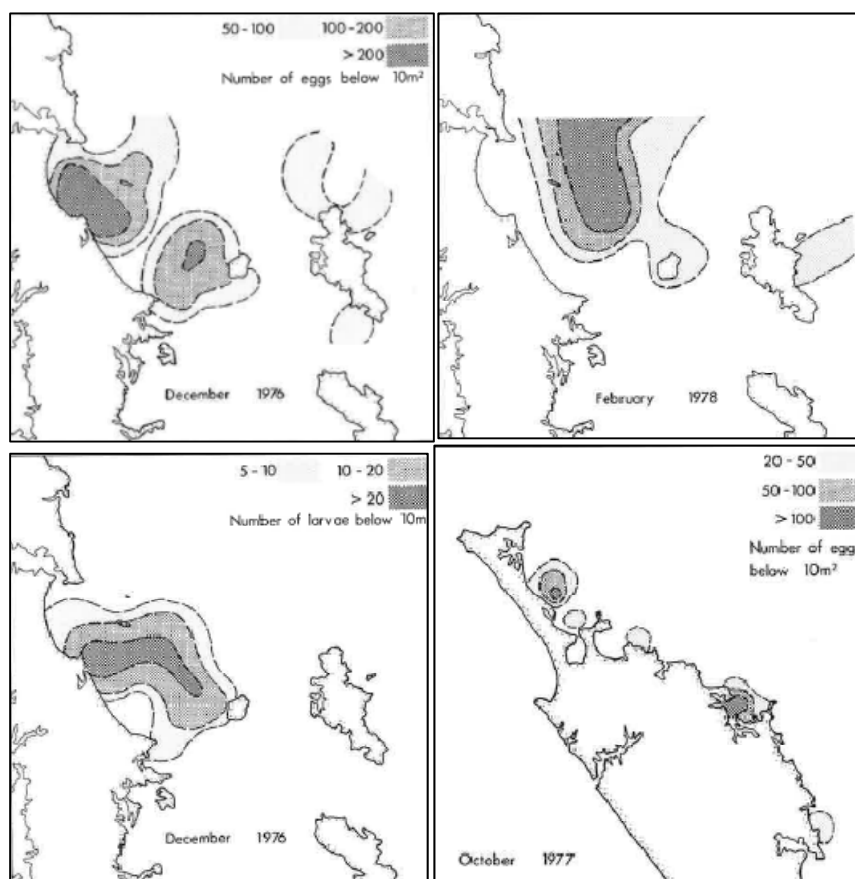


Figure 12: Distribution of red gurnard eggs in the outer Hauraki Gulf; December 1975, December 1976, and February 1978; and off east Northland, October 1977. (Source: figures 25–27 of Crossland 1982, reproduced with permission).

Nursery habitats

Recently settled juveniles (15–80 mm) are found in shallow harbours and estuaries over February–March, especially along the upper west coast North Island, but in low numbers only (e.g. Francis 2005, 2011a, Lowe 2013), suggesting that these are very peripheral habitats that contribute relatively few individuals to adult populations. Other reports of juvenile red gurnard in estuaries/harbours (in low numbers) include the Pauatahanui/Porirua inlets (Healy 1980), Lyttelton Harbour and Pegasus Bay (Staples 1971), and Days Bay, Wellington (Elder 1976). Sampling with the fine mesh gears used in those studies have not been undertaken in more coastal habitats. Very small fish (under 30 mm) are box-like in body shape, while larger juvenile red gurnard are very slender and cylindrical, probably allowing them to pass straight through the larger mesh nets used in standard trawl surveys (e.g. 40 mm in the upper North Island). Elder (1976) found large numbers of 2+ fish and a small percentage of 0+ fish in the Colville Channel area, and suggested that this area was close to nursery grounds stocked by spawning in the Craddock Channel. However, only one 110 mm 0+ juvenile (in Kikowhakarere

Bay, western Coromandel) was found in his search for likely nursery habitats in the eastern Hauraki Gulf; concurrent studies on other species reported a few juveniles (75 to 115 mm) from Orere Point, the “*Dab Patch*” (sand flounder) (east of Ponui Island, Firth of Thames) and Colville Bay in the Hauraki Gulf. Elder (1976) speculated that 0+ juveniles might occupy habitats not easily accessible to trawl and seine sampling such as rough ground.

Research trawl records show that 0+ and 1+ red gurnard (10–20 cm) are caught around much of the coast of the North Island in depths less than 100 m, with highest catches in northern areas including the Hauraki Gulf, east Northland, Bay of Plenty, Hawke Bay and on the northern west coast (up to 0.8 t.km⁻²) (Hurst et al. 2000a). Whilst fish as small as 10 cm have been sampled, numbers are not high and distinct cohorts are not apparent (Langley 1994). In the South Island, high catches in Golden and Tasman bays (up to 0.6 t.km⁻²) were thought to be evidence of a nursery area which supplied the west coast South Island population, where catches are dominated by older fish (Stevenson & Hanchet 2000b). Lyon & Horn (2011) aged red gurnard otolith collections from the west coast South Island/Tasman and Golden Bay trawl surveys of 2003, 2005, and 2007, and used the age/length keys to translate the survey length frequencies to age frequencies. Mean ages and lengths for fish sampled from off the west coast remained stable between 2003 and 2007, but Tasman/Golden Bay fish varied due to the strong influence of young fish entering these areas. West coast fish were larger and older than those in Tasman and Golden Bays, and appeared to move into deeper water as they grow. The catch composition for Tasman and Golden Bays contained a high proportion of young red gurnard. Mean fish size was 26–31 cm and mean age 2.5–3.3 years, across three strata covering the 20–70 m depth range. There was a strong cohort of 1+ fish in 2005. In earlier surveys in 1994 and 1995, there was a dominance by 1–2 year old fish, Lyon & Horn (2011) concluded that “*a nursery ground in Tasman and Golden Bays would explain the large numbers of small and young fish within this area. This raises the question, where do the west coast fish come from? If they migrate from the Tasman and Golden Bays nursery area south along the west coast, we might expect to see greater numbers of smaller fish in the northern west coast strata as compared to the southern strata. This trend does occur in the three southern most strata, but not in those north of Cape Foulwind. The red gurnard caught north of Cape Foulwind may be passing through that area during the March–April survey period and as a temporary and mobile population may not be sampled well by this survey*”.

From the east coast South Island surveys, 0+ and 1+ fish are caught in sufficient numbers to observe consistent annual progressions of length modes and year classes (Sutton 1997).

Adult habitats

Francis et al. (2002) described red gurnard as “*the most frequent species in the inshore assemblage. [with] the widest latitudinal range and third greatest depth range*”. It is most abundant in northern New Zealand, with consistently high catches in trawl surveys along the west coast and in the Bay of Plenty between 10 and 150/200 m (Langley 1994, Morrison et al. 2001 a, b). On the west coast, some exceptionally high catches have been recorded in some areas (e.g. Ninety Mile Beach) but with no clear spatial trends (Morrison et al. 2001a). In the Hauraki Gulf, catches have been variable, being scarce in some years of the survey, but in often higher abundances in the Colville and Craddock channels, and outer (deeper) gulf strata (Langley 1994, Morrison et al. 2002). Catches from east Northland surveys have been comparatively low (Langley 1994). A recent trawl survey (50–200 m) along this coastline produced low catch rates, apart from in shallow strata within the Bay of Islands (10–50 m) and around the Cavalli Islands (Jones et al. 2010, unpubl. data). In west coast South Island trawl surveys red gurnard are caught in all but a few stations, with the highest catches often recorded from Tasman and Golden Bay. In the east coast South Island surveys, red gurnard are generally

confined to depths of less than 100 m, with the highest catches north and south of Banks Peninsula, off Pegasus Bay, and between Timaru and Oamaru.

Adult migrations and movements

Elder's (1976) Hauraki Gulf study indicated that red gurnard make seasonal migrations associated with ontogeny and reproductive maturity, with fish moving into deeper water as they get older, and on a seasonal basis to spawn. He proposed a model based on catch rates where, broadly speaking, fish commenced a spawning migration from the Firth of Thames in September, reaching the Colville area during September and Craddock Channel during October, over about a six week period. Fish then stayed in these areas until winter, with fish migrating from Craddock Channel in June, and from Colville Channel in July/August, arriving back in the Firth of Thames in August. This in-shore, post-spawning migration of about 50 nautical miles therefore took 12 to 14 weeks. However, it was suggested that not all fish moved fully into the Firth of Thames, with possibly some migrating in so far as the Colville area. Not all fish were thought to migrate at the same time, only that a "pulse" of migration, to or from the spawning ground, took place over the months above (Elder 1976). It was postulated that spawning areas were chosen to enhance the subsequent transport of eggs/larvae into suitable nursery grounds. This movement model is a suggested dynamic only, and has not since been followed up by the tracking of individual fish through a tagging programme or other methodology.

Population connectivity

Differences in age distributions and growth rates between the east and west coasts of the South Island and the Hauraki Gulf (Sutton 1997) suggest that there are separate populations of red gurnard around New Zealand. Migratory behaviour is also strongly implied based on Elder's observations, which also suggesting that similar behaviours occur in other regions of New Zealand. More recent work has focussed on fundamental catch sampling in GUR 1 (west coast North Island; East Northland/Hauraki Gulf; Bay of Plenty, 2009–10 year, McKenzie et al. 2012) and GUR 2 (lower east coast North Island, Parker & Fu 2012). These studies were based on commercial catches, so relatively few small juvenile red gurnard were landed, and reporting was at relatively larger scales with no fine scale spatial breakdowns. Their objectives did not include any investigation or discussion of stock structure.

3.26 Rig (*Mustelus lenticulatus*)

Fisheries catch:

Commercial: 1260 t¹

Recreational: 200–450 t^{1*}

Sexual maturity:

Males: 4–6 years / ~85 cm^{2,3}

Females: 5–8 years / ~100 cm^{2,3}

Maximum age: 20 years / 150 cm (female)^{2,4}

Reproductive mode:

Aplacental viviparity

Gestation period:

11 months

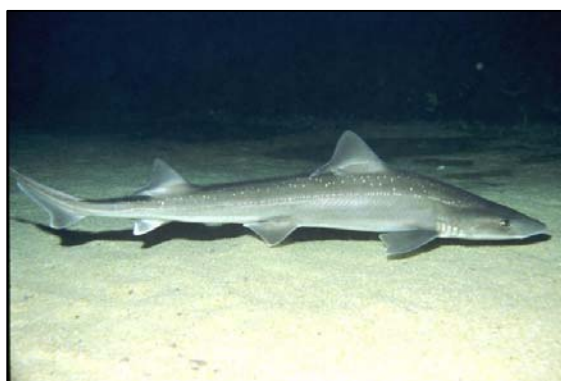


Photo credit: M. Francis, NIWA

¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ^{*}Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around these estimates; ²Francis & O Maolagáin (2000); ³Francis & Francis (1992); ⁴Francis (1997b).

Rig are endemic to New Zealand and found all round the coastline from the Three Kings to the southern edge of the Snares Shelf. They are rare on the Chatham Rise (being caught on Mernoo Bank, western edge of the Rise and at the Chatham Islands) and absent from the Campbell Plateau, despite suitable habitat existing in this area (NABIS). The known depth range is 0–600 m, but they are most common in shelf waters to about 100–200 m (Paul 2000). Rig are found mainly over soft sediment, feeding on a wide variety of benthic invertebrates, especially brachyuran and pagurid crustaceans, echinurans and molluscs.

Spawning

Rig aggregate annually in spring and summer in shallow coastal waters to breed. Gestation is believed to be around 10–11 months (Graham 1956, Francis & Mace 1980). The pregnant females enter estuaries and harbours to give birth in spring before mating again, occupying summer feeding grounds and leaving shallow waters in autumn (Francis 1979, figure 24). However, full-term pregnant females (i.e., those with embryos over 25 cm) have been recorded in relatively small numbers and the location of pupping and mating sites is not known. Graham (1956) recorded full-term and recently pupped females from Otago harbour between November and February, although more recent data is lacking from this area. King (1984) sampled commercial set net catches in Golden Bay between September 1980 and March 1981. Most females sampled were recently ovulated or were carrying developing embryos, with greatest numbers in less than 20 m water depths. Post-partum females were caught across the depth range. Full-term females were rarely caught (n=5), but when they were it was in depths greater than 20 m. Local fishers also reported that large numbers of full-term females were occasionally caught in deeper water (D. Falconer, P. O'Connor – pers. comm., in King 1984). There was a seasonal pattern to catches, with recently ovulated females dominating the spring catches (September–December) and declining over summer, whilst females carrying yolked embryos were more abundant in summer months. It was assumed that parturition took place “*outside the area*” in spring before the females moved inshore to breed and occupy summer feeding grounds such as “*The Banks*”. However, data on liver condition did not indicate that feeding in these shallow areas resulted in improved condition. Francis & Mace (1980) also noted that recently ovulated females were abundant in spring catches in Golden Bay and in the Kaikoura region on the east coast of the South Island. Females carrying late-term embryos were reported in this study, mainly in November, but numbers were again low (n=8). No depth information was given but the authors concluded that parturition occurred either offshore or in coastal areas not sampled in the study. Catches also indicated that high numbers of males are found in the Nelson region in spring (Massey & Francis 1989) and the later arrival of females suggesting that rig mate in Golden Bay-Tasman Bay area with females arriving after pupping elsewhere. Sampling in the Kaikoura region suggested that females were migrating through the area on their way to summer feeding grounds (shallow coastal waters). A later study focusing on Pegasus Bay recorded a small number of females with full term embryos between November and January (Massey & Francis 1989). In the North Island, small numbers of females with full-term embryos have been recorded in certain locations; large numbers of adults were reported to enter Pauatahanui Inlet and Porirua Harbour in October–December to feed, with pregnant females caught on several occasions (Healy 1980, Francis & Francis 1992). In his study of the upper Waitemata Harbour, Briggs (1980) noted “*an almost complete absence of adult female smoothhound in the harbour – only one of 213 individuals*”. This female was “*about to give birth to 9 fully formed juveniles*” and was caught a few weeks before the main spring sampling. In addition to these localized studies, Hurst et al. (2000a) reported records of female rig with embryos of over 24 cm from the west coast of the North Island, (particularly numerous from outside Kaipara Harbour north), the eastern part of the Outer Hauraki Gulf, Golden and Tasman Bays, as well as occasional records from east Northland, Kaikoura, Pegasus Bay, off Otago and the south-west South Island.

Once females have pupped it is thought that a rest period of about one month follows before breeding and spending the summer months feeding inshore (e.g. King 1984). In autumn females leave for deeper water, and information on mid-term pregnant females is scarce.

Egg and larval transport

Not relevant as embryos are internally gestated, and juveniles born fully-formed.

Nursery habitats

Young are either born in estuaries or large coastal harbours, or they make their way into these places after being born in nearby coastal waters (King 1984, Blackwell & Francis 2010). Juveniles remain resident for around 6–8 months, until water temperature starts to drop from February until May–June (Hendry 2004, M. Francis unpubl. data). By this stage they have undergone rapid growth to reach 45–50 cm. Larger juveniles (1+) occur more widely in coastal areas and immature fish are caught in commercial set net and trawl fisheries on the inner continental shelf around much of New Zealand (Francis & Smith 1988, Hurst et al. 2000a). Francis et al. (2012) compiled existing information on the distribution of 0+ rig and also conducted a nation-wide set net survey in selected sites. Information sources included research trawl surveys in inshore waters and a number of studies using other fishing methods such as set nets. They considered Kaipara, Raglan, Waitemata, Tamaki and Porirua harbours to meet the shark nursery criteria of Heupel et al. (2007), containing higher densities and abundance of 0+ rig than adjacent coastal waters, occupied for extended periods during summer–autumn and used repeatedly across years.

The Kaipara Harbour is likely to be the most important nursery area for rig in New Zealand. Large numbers of 0+ juveniles have been caught in set net surveys in various shallow muddy areas in January (Hendry 2004, Paparoa Creek), February (Francis et al. 2012, Arapaoa and Oruawharo Arms) and May (Francis, unpubl, between Shelley beach and Kaipara Heads), and similar suitable habitats exist throughout this large harbour. Further south, 0+ rig have also been caught in the Manukau (Hendry 2004, Morrison, unpubl. data) and Raglan harbours (Hendry 2004, Francis et al. 2012), and it is likely that Kawhia and Aotea harbours also support small populations, given the distribution of juvenile (0+ and 1+) rig recorded in research trawl catches along this coast (Figure 13). A series of set net surveys over a 30 year period consistently caught high numbers of 0+ rig in Pauatahanui Inlet of Porirua Harbour in summer and autumn, and this is considered a highly important nursery ground (Healy 1980, Jones & Hadfield 1985, Francis & Francis 1992, Hendry 2004, Francis et al. 2012). Records along the east coast of the North Island are sparser, with low numbers of juveniles reported from Wellington (King & Clark 1984), Poverty Bay (Francis 1985), and small numbers of 0+ and 1+ caught in trawl survey stations in the Hawkes Bay region. In the Bay of Plenty, low numbers of juveniles were caught in trawl surveys in the Whakatane coastal area and Hendry (2004) believed that Ohiwa harbour may be acting as a nursery. Newborn rig were caught in Tauranga harbour although a more recent set net survey failed to find any (Francis et al. 2012). The Upper Waitemata harbour (Briggs 1980, Francis et al. 2012) and Tamaki River (Hendry 2004, Francis, M. et al. 2011) were considered high value nurseries, with newborns caught in significant numbers in multiple surveys. Trawl surveys of the Hauraki Gulf and Firth of Thames have also caught both 0+ (n=105 over 23 years) and 1+ (n=621) rig, with the smaller size class occurring closer inshore. Hendry (2004) suggested that the Hauraki basin acts as a secondary nursery that juveniles move to following the first 6–8 months spent in the inner estuaries and harbours. There do not appear to be significant nurseries north of the Hauraki Gulf, with small numbers of 0+ and 1+ rig caught in Waikare Inlet, Bay of Islands (L.D. Ritchie, formerly MAF Fisheries, unpubl. data), but more recent surveys in that area and Parengarenga Harbour finding none (Hendry 2004).

In Blueskin Bay, Otago, Graham (1956) reported “*At no other locality [Blueskin Bay] have I seen so many young dogfish [rig] numbers of which showed by the placental attachment that they could not have been long born.*” However, more recent trawl surveys have caught only modest numbers of 0+ and 1+ rig (Hurst et al. 2000a, Hanchet unpubl. data) and targeted set net surveys here and in Otago harbour have caught either none or very few (Hendry 2004, Francis, et al. 2012, Francis unpubl. data). Further north on the east coast of the South Island, juvenile rig have been recorded, mainly in the shallow strata (less than 30 m) of inshore trawl surveys in Canterbury Bight and Pegasus Bay, both in the discontinued summer series and the winter surveys (April–May) as well as targeted trawl samples in Pegasus Bay (Francis & Francis 1992). These more recent surveys found both adult and juveniles (30–120 cm) to be most common in the 5–10 m depth range in the central, northern part of the survey area (Canterbury Bight, near Lake Ellesmere) (Beentjes et al. 2010a). Webb (1973) reported a single 0+ male rig (32 cm) from the Avon-Heathcote Estuary, while Francis & Mace (1980) reported anecdotal evidence from local fishers who described large numbers of small rig (35–45 cm) caught in early December off river mouths along the North Canterbury coast. Francis (unpublished) also reported that small numbers of 0+ rig have been caught in set net surveys in Akaroa and Lyttleton harbours. The inshore trawl survey of the west coast of the South Island regularly catches 0+ juvenile rig under 40 cm (Stevenson & Hanchet 2000b, MacGibbon & Stevenson 2013), particularly in Tasman and Golden Bays (see Figure 13). However, Francis et al. (2012) pointed out that numbers are relatively low (n=305, over a 52 year period across the whole of the South Island) and a number of targeted set net surveys in these areas have failed to catch 0+ juveniles (Hendry 2004, Francis, et al. 2012). Francis et al. concluded that it was difficult to determine the importance of these proposed South Island nursery grounds, given the low numbers of 0+ rig caught. However, higher numbers of 1+ rig (more than 900) have been recorded in trawl surveys around the coast and therefore bays, surf beaches and open coastline waters less than 10 m deep may function as nursery areas.

Thus estuaries, harbours and shallow coastal waters throughout much of mainland New Zealand appear to act as either primary or secondary nursery grounds for rig. Environmental data collected in the most recent set net survey suggest that muddy substrata in turbid parts of harbours which have a significant freshwater component especially support high abundances of 0+ rig (Francis et al. 2012).

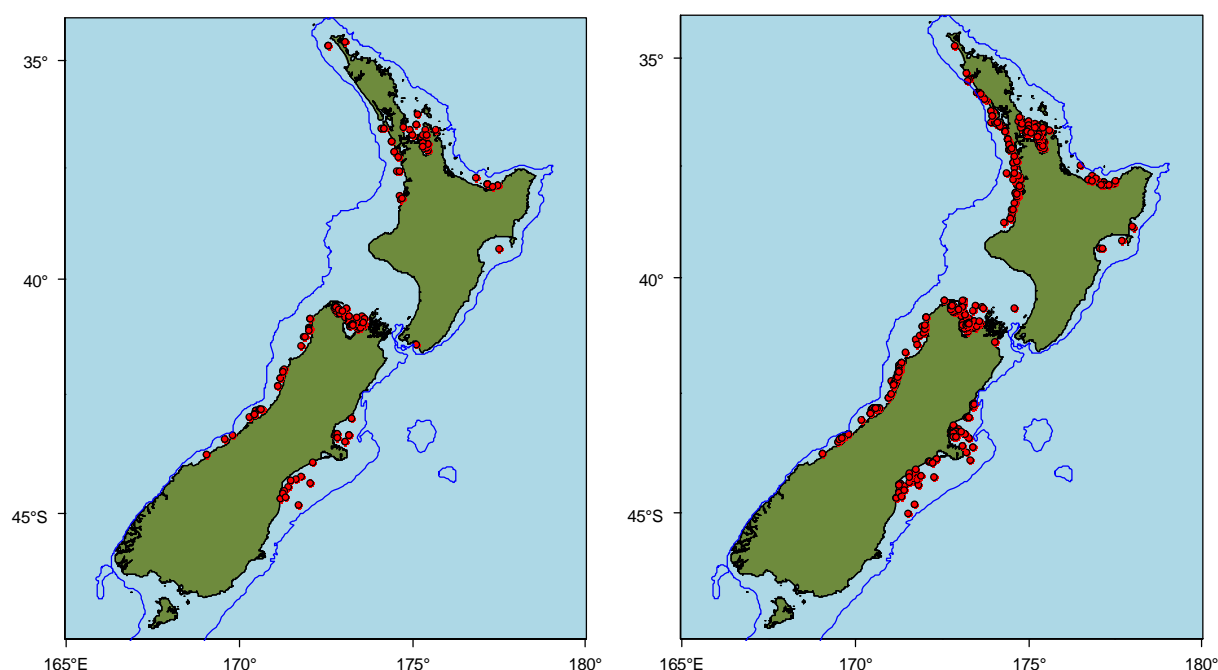


Figure 13: Distribution of small juvenile rig in research trawls 1960–2011. Left: rig less than 40 cm total length (N = 217 stations, 305 rig). Right: rig 40–50 cm total length (N = 643 stations, 911 rig). Blue line is the 200 m depth contour. (Source from Francis et al. 2012).

Francis (2013) acoustically tagged and tracked 14 juvenile 1+ rig (34–42 cm long, mean 38.8 cm) across the two arms of Porirua Harbour, Wellington. Over a period of up to four months over summer-autumn, fish showed clear site preferences, but those preferences varied among rig and over time. Most of the time was spent in large basins and on shallow sand and mud flats around the margins, with deep channels being avoided. Only one shark spent time in both harbour arms, indicating that there was little movement between the two. Home ranges spanned 2–7 km², with fish moving to outer harbour sites following some high river flow rates, and most leaving the harbour permanently during or soon after a river spike, suggesting that they were avoiding low salinity water. During the summer movements were strongly diel, with this pattern weakening in autumn. Repeated use of the same day and night sites was interpreted as indicating directed movements, rather than random ones.

Adult habitats

In east coast South Island trawl surveys, rig were caught in fewer than 20% of stations, being most common in less than 30 m of water (Hurst et al. 2000a). In west coast South Island surveys, catches were spatially variable with large females noted as more abundant in Tasman and Golden Bay and large males more abundant on the west coast (Hurst et al. 2000a). Trawl surveys around the North Island indicate small but consistent catches between Cape Reinga and Mana Island on the west coast, low numbers in east Northland, and higher catches in the inner Hauraki Gulf including the Firth of Thames, Tamaki Strait and Motuihe channel, and the eastern Bay of Plenty between Whakatane and Cape Runaway (Langley 1994).

Rig are caught commercially using targeted set net fishing (Blackwell et al. 2006), with key fisheries occurring off Ninety-Mile Beach, Kaipara Harbour, Manukau Harbour, South Taranaki Bight, Tasman/Golden Bay, Canterbury Bight, Kaikoura and Hauraki Gulf (MPI 2012). These fisheries are highly seasonal, peaking in spring and summer, and relate to the inshore migration of adults to breed (Francis 1979). Hartill (2004) reported the targeted set net fishery in the Kaipara Harbour for rig which occurs from September through to December. Francis & Mace (1980) sampled commercial gill net catches from Kaikoura and Nelson, where most catches were taken between September and April. Between Kaikoura Peninsula and the Conway River, rig were caught in 50–140 m depth from November to March. In Nelson, commercial fishing shifted from the middle of Tasman and Golden Bays in December to a shallow (less than 10 m depth) area called “*The Banks*” inside Farewell Spit until late March. Similar patterns are reported from other local fisheries. Francis and Mace also commented that rig were only caught in commercial trawls in small quantities on the continental shelf in winter. Occasional catches in much deeper water indicates a range that includes continental slope habitats.

Adult migrations and movements

Rig are highly mobile, undergoing seasonal inshore–offshore migrations, presumably relating to their reproductive cycle. The winter habitat of rig is poorly known with low commercial catches at this time of year, but they are believed to disperse across the continental shelf and possibly deeper. Commercial fishers have reported the early spring appearance of adult rig in shallow shelf waters in the vicinity of the Hikurangi Trench (Kaikoura) and the Waitaki Canyon near Timaru and Oamaru (Francis 1988, Figure 14), and fishers believe rig may return to coastal waters via these features or possibly overwinter in their vicinity. Graham (1956) reported that commercial fishers long lining for

groper at 'North Reef' caught rig in mid water in around 150 m depth during winter, to the extent that they were "*considered a nuisance*".

A study carried out between 1978 and 1988 tagged 2386 rig from commercial set nets and research trawls, mainly around the South Island. Francis (1988) reported initial results from almost 400 recaptures. Most tagging and recaptures occurred over the summer months. Over half the rig tagged were recaptured over 50 km away and half the females had moved over 200 km, with one individual travelling 1159 km from the Snares Islands to Golden Bay. Females travelled further than males, and information from those tagged on the east coast of the South Island, suggests that mature females made greater journeys than immature ones. Both sexes moved up and down the east coast of the South Island between Foveaux and Cook Strait, with six females travelling as far as the west coast of the North Island and one male reaching the west coast of the South Island. Females tagged off Kaikoura and in Pegasus Bay were all recaptured further south (apart from one individual), including the inshore Canterbury Bight. Females tagged off Timaru and Oamaru in the Canterbury Bight showed a strong pattern of northward movement with a primary displacement peak of 300 km, coinciding with Pegasus Bay and Kaikoura. There was more variation in the direction of male movement. Most rig tagged in Golden and Tasman Bay were recaptured close by and females on the west coast appeared mainly to move northwards, many into Golden Bay and Tasman Bay, but some females being recaptured on the west coast of the North Island and one female caught on the east coast of the North Island (Northland).

Population connectivity

Francis (2010) reanalysed the (updated) rig tag return discussed above, to assess the appropriateness of the current QMA boundaries. Rig are managed in five stocks. It was concluded that males rarely move outside the release QMA, even after 5 years at liberty. Around 30% of females moved beyond the release QMA boundaries within 2–5 years, but this movement was rarely beyond the adjacent QMA.

Companion reviews of genetic studies, growth rates, length at age and weight, the location of nursery grounds and vertebral counts provided little information suggesting the existence of separate stocks (Blackwell & Francis 2010). Length at maturity data, however, suggested that rig from SPO 1 east matured at a smaller size than South Island stocks (SPO 3 and 7) and could form a distinct stock. Furthermore, long-term differences in CPUE trends between the Manukau Harbour and other areas of SPO 1 and also between the west coast South Island and Tasman and Golden Bays, suggest that movement of rig may be insufficient to homogenise differences in population density over these smaller spatial scales, but stock separation was thought to be unlikely and the differences were likely to result from processes acting below the stock level (Blackwell & Francis 2010). Francis (2010) concluded that based on the low movement of adults the current QMAs were appropriate for rig.

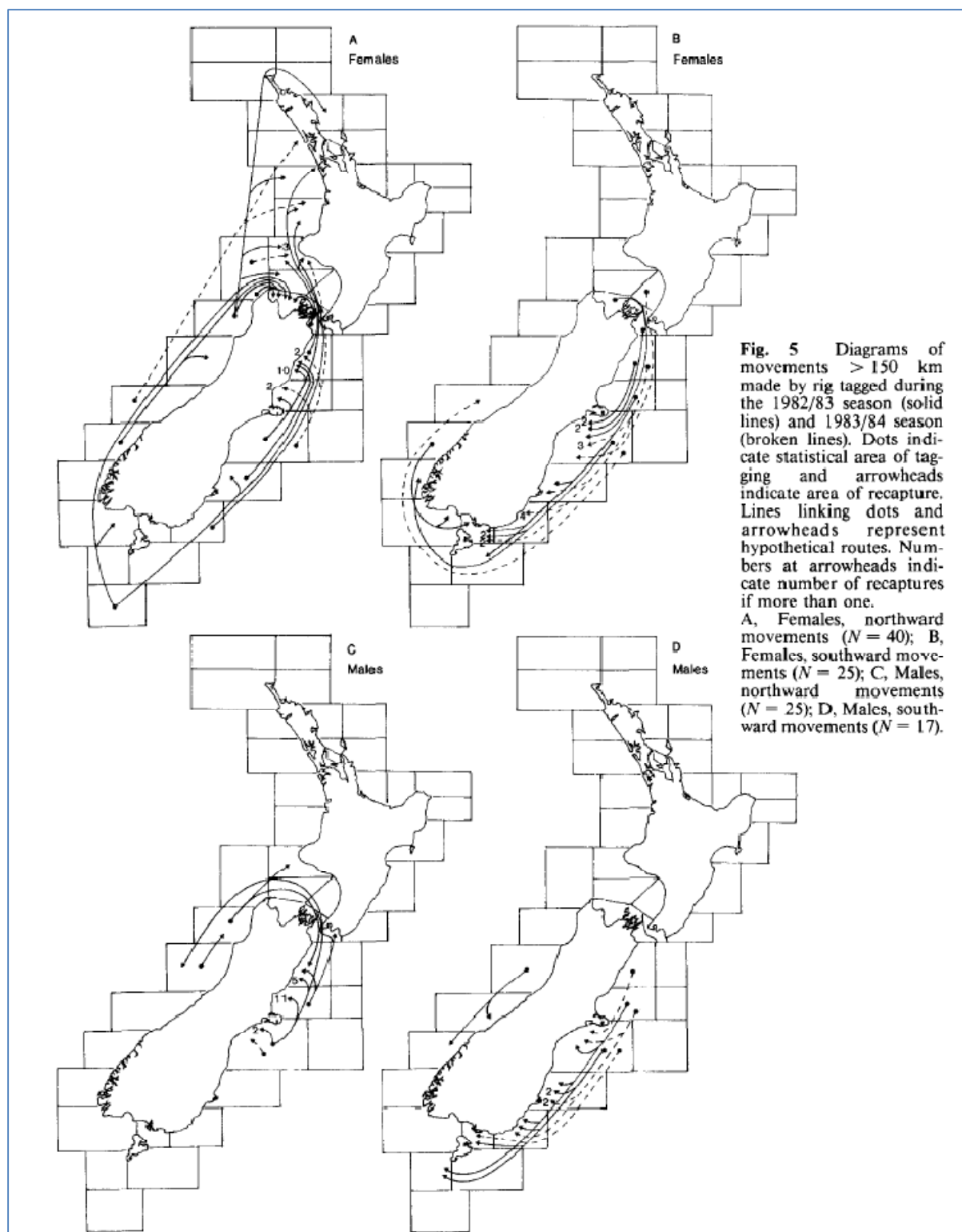


Figure 14: Movements of rig tagged between 1978 and 1988. Source: Francis (1988), reproduced with permission.

3.27 Rough skate (*Zearaja nasuta*)

Fisheries catch:

Commercial: 1882 t¹

Recreational: very rare¹

Sexual maturity: males: 52 cm / 4 years,
females: 59 cm / 6 years¹

Maximum age: female 70 cm / 9 years²

Pelagic phase duration:

Eggs: None, benthic egg cases laid on seafloor¹



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¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ²Francis et al. (2001a, b).

Rough skate are endemic to New Zealand, and are abundant on the mid to outer continental shelf throughout the mainland, but are more abundant around the South Island down to depths of 500 m. Skates in general are considered one of the most threatened groups of marine species worldwide, with localized extinctions well documented (Dulvy et al. 2000).

Rough skate are known to feed on fish, shellfish, crabs and worms (Cox & Francis 1997). Rough skate are smaller than smooth skate, reaching around 79 cm pelvic length (snout tip to posterior margin of pelvic fins), compared to 158 cm pelvic length for smooth skate (Francis 1997c).

Spawning

The timing of mating for rough skate is unknown, but the occurrence of females carrying egg cases ready for extrusion and extruded egg cases caught in trawls or washed up on beaches can indicate the location of nursery areas. Female skates lay pairs of eggs in leathery cases on the seabed. Graham (1939b) describes “numerous” rough skate egg capsules being collected in Blueskin Bay and washed up locally after storms and females carrying capsules “almost ready for extrusion” were taken in October to January and in March. Female rough skate carrying ovulated eggs or egg cases have been collected in research trawl surveys along the east and west coasts of the South Island and in Tasman and Golden Bays, with the highest density of skate in egg-laying condition recorded on the east coast south of Banks Peninsula during December and January (Francis 1997c, O'Driscoll et al. 2003). From information available on timing, it seems likely that egg laying occurs in shallow depths during spring and summer (Francis 1997c), although the similar North Atlantic species *Dipturus laevis* was found with fully formed egg capsules in winter, with young thought to hatch in late spring and early summer (Bigelow & Schroeder 1953). The habitat preferences of egg-laying females are unknown, but anecdotal diver observations from the large European skate *D. batis* report egg cases as being “loose” on the seabed and perhaps very vaguely “wedged in between rocks” (Neal et al. 2008). Graham (1956) observed that one set of horns from the skate capsules he collected was always longer and showed signs of erosion and deterioration and believed that females laid capsules so that they became partly buried in sandy sediments. It is likely that females lay more than one pair of eggs over the course of the season but for New Zealand species, the number is unknown. Similar large skate species have been reported to produce 40–50 eggs in a season (Du Buit 1976, Casey & Myers 1998), although anecdotal reports suggest that female *D. batis* may only breed every other year (Little 1997) and Ebert

(2005) showed that some skates may be restricted to a very small number of spawning seasons in their life-time, as low as one in some cases.

Egg and larval transport

Not relevant.

Juvenile habitats

The incubation time for rough skate embryos is unknown, but is likely to be 4–5 months (Graham 1956). Francis (1997c) presumed that rough skate hatch at about 10 cm PL (pelvic length), based on the length of the smallest free-living specimens. Francis (1997c) examined length frequency data collected on research trawl surveys and found that rough skate of less than 40 cm appear to be confined to depths less than 75 m along the east coast of the South Island and were also recorded in reasonable numbers off the east coast of the North Island. Around the Stewart-Snares shelf, very few small fish were encountered, occurring in depths less than 150 m, whilst in Tasman and Golden Bays, small numbers of rough skate under 40 cm and none over 60 cm were caught in depths of 20–70 m (Stevenson 1998). It was also noted that rough skate as small as 10–13 cm were recorded from Otago throughout the year in 1982–83 by S. Hanchet (unpubl. data). In a more recent analysis of trawl survey data, O'Driscoll et al. (2003) found immature rough skate in less than 200 m all round the mainland, but most frequently around Banks Peninsula. Catches around Southland were low and the largest catch from a single tow was off Wairarapa (407 kg km⁻²).

Adult habitats

Rough skate are abundant on the mid to outer continental shelf, but are less common on the Campbell Plateau, around the Sub-Antarctic Islands, and on the Challenger and Chatham Rise (Anderson et al. 1998, McMillan et al. 2011). Rough skate have a depth range that extends from shallow water down the continental slope, being more abundant inshore and rare in depths greater than 500 m. Inshore trawl surveys along the west coast of the South Island have caught rough skate in around half of the stations, with highest abundances in less than 200 m. Off the east coast of the South Island, occurrence varied from 26–52% of stations for rough skate (Beentjes & Stevenson 2000). There was a similar frequency of occurrence in the historical summer time series for rough skate (Beentjes & Stevenson 2001). Highest catch rates for rough skates were recorded in depths less than 200 m from Pegasus Bay to the Canterbury Bight, as well as around Stewart Island. Francis (1997c) found no latitudinal trend other than lower catch rates south of 49°S. Typically, catch rates in research surveys for both skate species combined are usually less than 20 kg km⁻², but can reach 200–300 kg km⁻². Generally both New Zealand skate species are caught as bycatch in demersal trawl fisheries targeting other species such as red cod, flatfish and barracouta, but are also taken as a bycatch of bottom longlines, with significant bycatch reported from the ling fishery on the Bounty Plateau.

No information is available about specific habitat preferences of rough skate, but similar to other large skate species such as *Dipturus laevis* and *Dipturus batis* from the North Atlantic, they are most commonly found over soft sediment habitats including mud, sand and gravel substrates, where they are vulnerable to towed fishing gear. In an assessment of essential fish habitat for *D. laevis*, other than broad sediment characteristics, a temperature range of 1–20° and 32–36 ppt salinity were used to define habitat (Packer et al. 2003). Given their depth and latitudinal range, rough skates are likely to have a similarly broad temperature tolerance.

Adult migrations and movements

Little biological information is currently available for rough skate: but their broad distribution around New Zealand, and more specific nursery areas for egg-laying, suggests that seasonal movements for

reproductive purposes occur. The east coast of the South Island between Banks Peninsula and Otago appears to be an area where particularly high numbers of juvenile rough skate are recorded.

A skate tagging programme has recently been implemented on research trawl surveys and should eventually provide information on movements, home range, and possibly growth, although the numbers tagged are relatively modest. Elsewhere, the movements of related large skate species have been studied and suggest high site fidelity in some species. A tag and recapture program implemented for *D. batis* in northeastern Scotland recorded 147 recaptured individuals, of which only 5 had travelled more than 20 km (Little 1998, Wearmouth & Sims 2009). Such behaviour makes *D. batis* very vulnerable to local extinction and the disappearance of this species from waters around the United Kingdom and Europe has been well documented (Brander 1981, Walker & Hislop 1998), with remnant populations now remaining only in areas of Scotland unsuitable for commercial fishing (Shark Trust pers. comm.).

Population connectivity

Nothing is known about stock structure or population structuring in rough skate.

3.28 Smooth skate (*Dipturus innominata*)

Fisheries catch:

Commercial: 609 t¹

Recreational: very rare¹

Sexual maturity: 93 cm / 8 years, females: 112 cm / 13 years¹

Maximum age: female 155 cm / 28 years²

Pelagic phase duration:

Eggs: None, benthic egg cases laid on seafloor¹



¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ²Francis et al. (2004).

Smooth skate are endemic to New Zealand, and abundant on the mid to outer continental shelf throughout the mainland. Skates in general are considered one of the most threatened groups of marine species worldwide, with localized extinctions well documented (Dulvy et al. 2000).

Forman & Dunn (2012) found that the diet of smooth skate on the Chatham Rise consisted of both benthic and natant decapods and a variety of fish, including fishery discards. The most important benthic decapods in their diet were soft-sediment dwelling scampi (*Metanephrops challengeri*) and squat lobster (*Munida gracilis*), and fishes; including hoki (*Macruronus novaezelandiae*), sea perch (*Helicolenus barathri*), and a variety of rat-tails (Macrouridae). The proportion of fish and discards increased with size of individuals. Smooth skate is one of the largest skates in the world, reaching at least 158 cm pelvic length (snout tip to posterior margin of pelvic fins) (Francis 1997c). Anecdotal records of very large skates (assumed to be smooth skate) were reported by Graham (1956) including one from Otago Museum measuring over 2 m, and another caught off Shag Rock, Sumner and reported in the Lyttleton Times in 1862 that measured over 3 m and weighed 190 kg. Francis (1997c) also noted a skate measuring 2.53 m caught off Milford Sound during a 1909 Government Trawling Expedition (Waite 1909, cited in Francis 1997c).

Spawning

The timing of mating for smooth skate is unknown, but the occurrence of females carrying egg cases ready for extrusion and extruded egg cases caught in trawls or washed up on beaches can indicate the location of nursery areas. Female skates lay pairs of eggs in leathery cases on the seabed. The large smooth skate recorded off Milford Sound in the 1909 Government Trawling Expedition was carrying two developing uterine eggs and Waite also reported egg cases at trawl stations between Hawke Bay and Foveaux Strait, and at the Chathams (Francis 1997c). O'Driscoll et al. (2003) found just 20 records of smooth skate females with ovulated eggs or egg cases. Those in egg-laying condition were found off the South Island, with one occurrence in Tasman Bay. From information available on timing, it seems likely that egg laying occurs in shallow depths during spring and summer (Francis 1997c), although the similar North Atlantic species *Dipturus laevis* was found with fully formed egg capsules in winter, with young thought to hatch in late spring and early summer (Bigelow & Schroeder 1953). The habitat preferences of egg-laying females are unknown, but anecdotal diver observations from the large European skate *D. batis* report egg cases as being “loose” on the seabed and perhaps very vaguely “wedged in between rocks” (Neal et al. 2008). It is likely that female skate lay more than one pair of eggs over the course of the season but for New Zealand species, the number is unknown. Similar large skate species have been reported to produce between 40–50 eggs in a season (Du Buit 1976, Casey & Myers 1998), although anecdotal reports suggest that female *D. batis* may only breed every other year (Little 1997) and Ebert (2005) showed that some skates may be restricted to a very small number of spawning seasons in their life-time, as low as one in some cases.

Egg and larval transport

Not relevant.

Juvenile habitats

The incubation time for smooth skate embryos is unknown, but is likely to be 4–5 months (Graham 1956). Francis (1997c) presumed that smooth skate hatch at about 17 cm PL (pelvic length), based on the length of the smallest free-living specimens. The east coast of the North Island was found to be an area where juvenile smooth skate (less than 60 cm) were predominant (Francis 1997c), although O'Driscoll et al. (2003) found juvenile smooth skate to be widespread over much of the New Zealand shelf including the Chatham Rise. Juveniles were also recorded in areas where adults have not been, such as the north and west of the North Island, including the Hauraki Gulf, where the highest single catch was recorded (569 kg km⁻²). Other areas of higher catches were south of Banks Peninsula and the west coast of the South Island. The highest catch rates were recorded in depths less than 200 m, but both immature and adult smooth skate appeared to have a bimodal depth range with peaks at 100 m and 400 m, although it was noted that this may reflect patterns of survey coverage (O'Driscoll et al. 2003).

Adult habitats

Smooth skate are abundant on the mid to outer continental shelf, and also occur on the Campbell Plateau, around the Sub-Antarctic Islands, and on the Challenger and Chatham Rise (Anderson et al. 1998, McMillan et al. 2011). Both New Zealand skate species have a depth range that extends from shallow water down the continental slope, with rough skate being more abundant inshore and rare in depths greater than 500 m and smooth skate rare beyond 700 m. Inshore trawl surveys along the west coast of the South Island have caught smooth skate in around half of the stations, with highest abundances in less than 200 m. The highest catches of smooth skate occurred south of Greymouth (Stevenson & Hanchet 2000b). Off the east coast of the South Island, occurrence varied from 27–59% for smooth skate (Beentjes & Stevenson 2000). There was a lower frequency of occurrence in the historical summer time series for smooth skate (Beentjes & Stevenson 2001). Highest catch rates of

smooth skate were recorded in depths less than 200 m from Pegasus Bay to the Canterbury Bight, as well as around Stewart Island. Francis (1997c) found no latitudinal trend other than lower catch rates south of 49°S. Typically, catch rates in research surveys are usually less than 20 kg km⁻², but can reach 200–300 kg km⁻². Generally smooth skates are caught as bycatch in demersal trawl fisheries targeting other species such as red cod, flatfish and barracouta, but are also taken as a bycatch of bottom longlines, with significant bycatch reported from the ling fishery on the Bounty Plateau.

No information is available about specific habitat preferences of smooth skate, but similar to other large skate species such as *Dipturus laevis* and *Dipturus batis* from the North Atlantic, they are most commonly found over soft sediment habitats including mud, sand and gravel substrates, where they are vulnerable to towed fishing gear. In an assessment of essential fish habitat for *D. laevis*, other than broad sediment characteristics, a temperature range of 1–20° and 32–36 ppt salinity were used to define habitat (Packer et al. 2003). Given their depth and latitudinal range, smooth skates are likely to have a similarly broad temperature tolerance.

Adult migrations and movements

Little biological information is currently available for smooth skate: but their broad distribution around New Zealand, and more specific nursery areas for egg-laying, suggests that seasonal movements for reproductive purposes occur. The east coast of the North Island may be an important area for smooth skate. However, the broad distribution of juvenile smooth skate in particular, may be evidence of multiple nursery areas around the mainland serving multiple local populations.

A tagging programme has recently been implemented on research trawl surveys and should eventually provide information on movements, home range, and possibly growth, although the numbers tagged are relatively modest. Elsewhere, the movements of related large skate species have been studied and suggest high site fidelity in some species. A tag and recapture program implemented for *D. batis* in northeastern Scotland recorded 147 recaptured individuals, of which only 5 had travelled more than 20 km (Little 1998, Wearmouth & Sims 2009). Such behaviour makes *D. batis* very vulnerable to local extinction and the disappearance of this species from waters around the United Kingdom and Europe has been well documented (Brander 1981, Walker & Hislop 1998), with remnant populations now remaining only in areas of Scotland unsuitable for commercial fishing (Shark Trust pers. comm.).

Population connectivity

Nothing is known about stock structure or population structuring in smooth skate.

3.29 Sand flounder (*Rhombosolea plebeia*)

Fisheries catch:

Commercial: 2467 t^{1*}

Recreational: 148–899 t^{1*}

Sexual maturity: 18–25 cm males / 2 years², 25–30 cm females³

Maximum age: 3 years^{3,4,5}

Pelagic phase duration:

Eggs: 112–120 hours⁶

Larvae: > 10 days⁶



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¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; *Landings for eight combined species of flat fish. Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around use of these data; ²Colman (1974); ³Mundy (1968); ⁴Raj (1973); ⁵Setyono (1996); ⁶Robertson & Raj (1971).

The sand flounder is a demersal flatfish belonging to a group known as right-eyed flounders and is found in estuaries, embayments and shallow coastal regions (to a depth of 100 m) around the coast of New Zealand (Anderson et al. 1988, Francis et al. 2005). Juvenile fish feed largely on amphipods, while decapods, sedentary polychaetes and cumaceans form the bulk of the adult diet (Mundy 1968). In general, female sand flounder can reach a maximum size larger than the males (Setyono 1996). Sex ratios of sand flounder (derived from data collected by otter trawl) are skewed towards females, with ratios of males to females of 1:3.6 identified by Setyono (1996). As one of the smaller members of the flatfish group, sand flounder are characterised by small size, rapid growth, short lifespan and relatively high fecundity (Jellyman 2011). There are significant flatfish fisheries in the Hauraki Gulf, Kaipara and Manukau Harbours (Paul 2000), and Tasman Bay and the Canterbury Bight (MPI 2012).

Spawning

Sand flounder in the Hauraki Gulf have been found to spawn from June to November in waters to the east of Waiheke and Ponui Islands, at the northern end of the Firth of Thames (Colman 1973). Spawning took place in water depths of 27–36 m. Off Canterbury, sand flounder probably spawn in two locations; near Akaroa Heads, and in the vicinity of Timaru (Colman 1978). A general southward movement of adult sand flounders off the east coast of the South Island presumably has the effect of maintaining flounder populations over the same stretches of coast, since planktonic eggs and larvae must be carried northwards by the Southland current (Tunbridge 1966b, Heath 1972, Colman 1978).

In Wellington Harbour, the presence of new recruits under 25 mm) over most of the year (Smith & Francis 1984) supports observations of a long spawning period for this species in Wellington Harbour (Mines 1975, Wilkinson 1977). Pulses of new recruits indicated both summer and winter spawning. Robertson & Raj (1971) described the eggs and embryonic development for this species.

Egg and larval transport

Rhombosolea spp. larvae have been sampled in the northern Hauraki Gulf through August to November (Tricklebank et al. 1992), probably consisting of sand and yellow-belly flounder individuals. Sampling at the entrance to Whangateau Harbour, known to support populations of juvenile sand flounders (Grogan 1982, Park 1984), found larvae to be present from June to February, with a peak in November (Roper 1986). Larvae have also been recorded from Otago Harbour,

Papanui Inlet, and Coopers Inlet in low numbers by Roper & Jillett (1981), from Pauatahanui Inlet (Healy 1980), and from the Avon-Heathcote Estuary (Knox & Kilner 1973).

Hickford & Schiel (2003) conducted ichthyoplankton surveys off Kaikoura, and recorded sand flounder larvae as being relatively common, and being more common during sampling over full moon periods.

Nursery habitats

Juveniles are seasonally very abundant in sheltered estuaries and harbours, and have been recorded from many estuaries around New Zealand (see numerous references in Hurst et al. 2000a). Juveniles are generally confined to the shallow tidal flats and along the shores near stream mouths. Increases in juvenile abundance were found over summer and winter in Wellington Harbour (Smith & Francis 1984), in October–December, and May–August in Pauatahanui Inlet (Healy 1980), while no seasonal trends were apparent in Waimakariri Estuary (Eldon & Kelly 1985). Seasonal sampling in the Pahurehure Inlet (Manukau Harbour) found high densities of small juveniles (25–100 mm) in summer along low-tide channel bank edges (Morrison 1998). Much lower densities of larger animals (75–150 mm) were present in the adjacent low-tide channels (consistent with findings by Smith & Benson 1980 in Wellington Harbour). Through autumn and winter the density of juveniles on the edge of the banks dropped substantially, while densities out in the channels proper increased. The average size of fish on the bank edges showed no change over a six month period, suggesting a combination of continued recruitment of smaller fish and emigration of larger fish. By winter, the highest densities of animals were located in 5–10 m water depth. This was taken to be evidence of an ontogenetic shift with age/size between estuarine habitats from shallow to deeper waters (Morrison 1998). National scale estuarine fish sampling by Francis et al. (2011) recorded them from all of the 69 harbours sampled, and in 71% of sites sampled. They tended to become more common in the upper parts of estuaries, with Morrison et al. (2002) recording them as the second most common demersal species (after exquisite gobies) sampled over mudflats in the upper Manukau Harbour. Higher catch rates were made during night sampling, for both high and low tides, although it was not known if this was a spatial behaviour change, or a change in gear selectivity. Fish were sampled from across the tidal flats (one kilometre wide) during high tides, showing that fish actively migrated into intertidal areas with the tides.

Between 1964 and 1966, more than 15000 sand flounder (15 cm to over 30 cm; 87% less than 25 cm) were externally tagged in three Christchurch region estuaries (Avon-Heathcote, Lyttelton, and Akaroa) (Figure 15) (Colman 1978). Recaptures were recorded from recreational and commercial fishers, as well as some by researchers: 3307 tagged fish were returned with sufficient associated location data to be used to assess movement.

Most fish left the estuarine tagging areas within a year. Increasing returns from coastal areas, in particular Pegasus Bay and the waters off Akaroa Head, occurred from August to November, and this was taken to be when most of the flounder exited the estuaries. This was at an estimated age of two years (Mundy 1968), at about 23 cm for females, and ‘rather less’ for males (Colman 1978). Few tagged fish were caught in the estuaries above this size. Tagged flounder from the Avon-Heathcote and Lyttelton estuaries were found in the same coastal areas, both north and south of Banks Peninsula. Tagged flounder from Akaroa Harbour displayed a different movement dynamic, with most fish being recaptured in the Canterbury Bight rather than Pegasus Bay.

A patch known as the ‘Winter Ground’ 15–20 km southeast from Timaru, is a known spawning ground for sand flounders, while an area in 30–45 m water depth off Akaroa Heads is thought to be a

second spawning ground (Colman 1978). Tagged fish from all three estuaries were found together during the spawning season. This would result in fish moving south to spawn in the Southland Bight providing eggs and larvae that would eventually metamorphose near Banks Peninsula and its nursery bays, while fish spawning near Akaroa Heads would provide eggs and larvae for settlement into Pegasus Bay and its estuaries (Colman 1978). This work directly and empirically linked adult sand flounder populations to three estuarine nursery grounds. Similar spatial patterns of high juvenile sand flounder abundances, but low numbers of adults, are seen across estuaries nationally (Morrison et al. 2002, Francis et al. 2005, 2011), with several commercial fishers noting that adult sand flounders (also known as ‘dab’s and ‘diamond-backs’) are not a significant component of flounder catches inside estuaries (Anon pers. comm.).

Adult habitats

Sand flounder have been caught in research trawls in inshore (less than 100 m depth) areas, mainly around the northern North Island and in Tasman Bay, but extending down the South Island to Otago (Anderson et al. 1998).

Adult migrations and movements

In a study of tagged adult sand flounder in Tasman Bay, Tunbridge (1966a) found that fish moved from the deeper offshore water (11–18 m) on to the shallow water beaches and mudflats, with a maximum average distance moved of 365 m per day (see Figure 23 in Yellow-belly flounder section). However, only 8 tags were returned from the tag-and-released of 507 fish (1.5%). He also reported that an earlier study by Street (1959–1963, report not available) which tagged sand flounder off the Otago Peninsula found the majority of fish to be recaptured at the tagging site, although there was also a “*significant southwest movement over all the major flatfish grounds, in addition to a movement into tidal estuaries*”. The greatest distance moved was 200 miles to the south (presumably the Foveaux Strait area).

Colman (1974, Figure 16) studied the movements of sand flounder in the Firth of Thames using 1968–70 fishing statistics, trawl surveys, and tagging experiments. In October and December 1970, 339 sand flounders (200–320 mm) were tagged; with 36 returns (11%) with a known recapture location. Only one fish moved outside the Firth, being recaptured off Tairua on the eastern side of the Coromandel Peninsula. All fish recaptured in October and December were from the Firth proper, but in December and January most returns were from the Waihou River, which exits into the Firth of Thames. There was no evidence of significant emigration from the study area, and it was concluded that movements were local, consisting principally of offshore movement to spawn in winter and spring, and of onshore movement in the summer. Sand flounder occurred in shallow water (less than 5 m) during their second and subsequent summers and in deeper water (down to 30–40 m) during the winter.

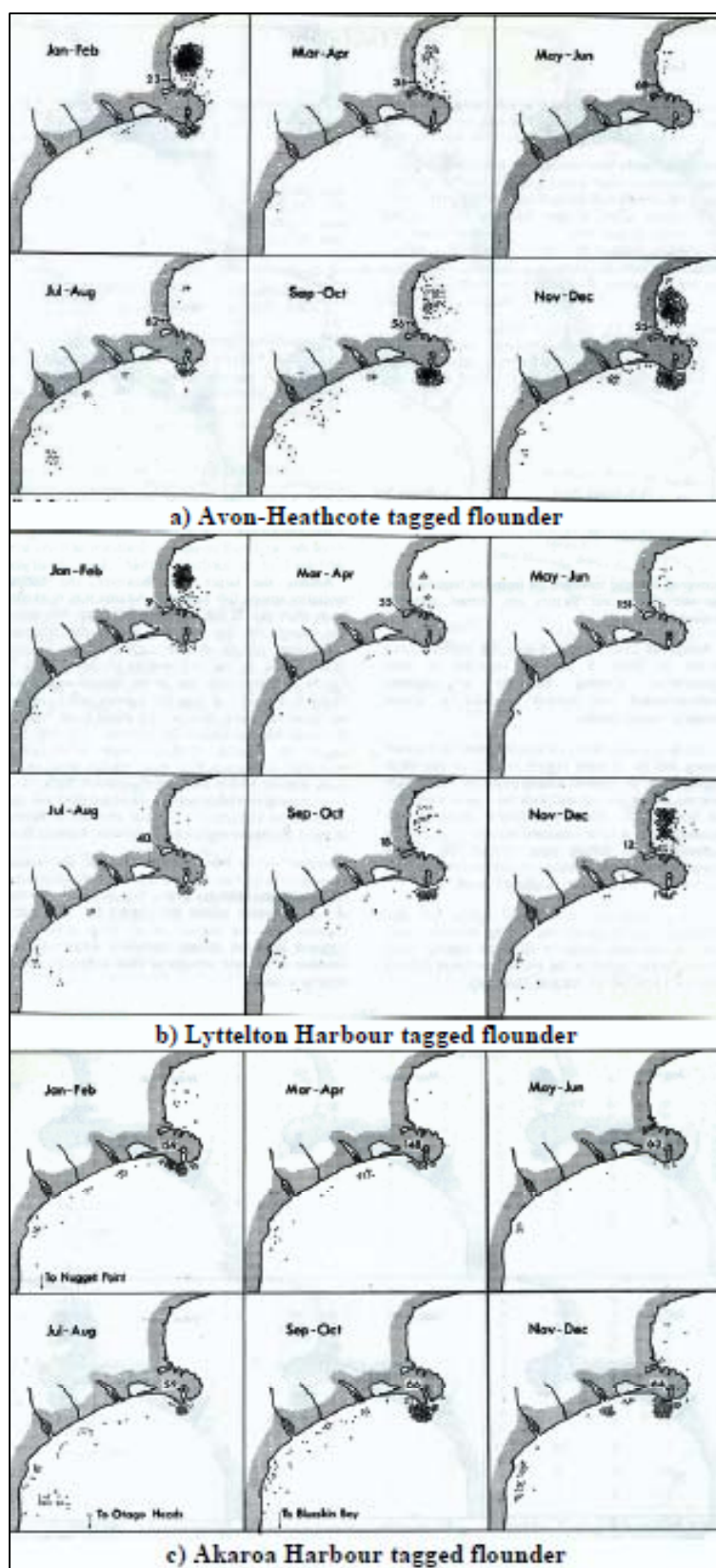


Figure 15: Positions of recapture of sand flounders tagged in the Avon-Heathcote, Lyttelton and Akaroa estuaries, and subsequently recovered outside the tagging area at different times of the year. Numbers recaptured inside the estuary are given as a number. Source: figures 8, 9 and 10, from Colman (1978).

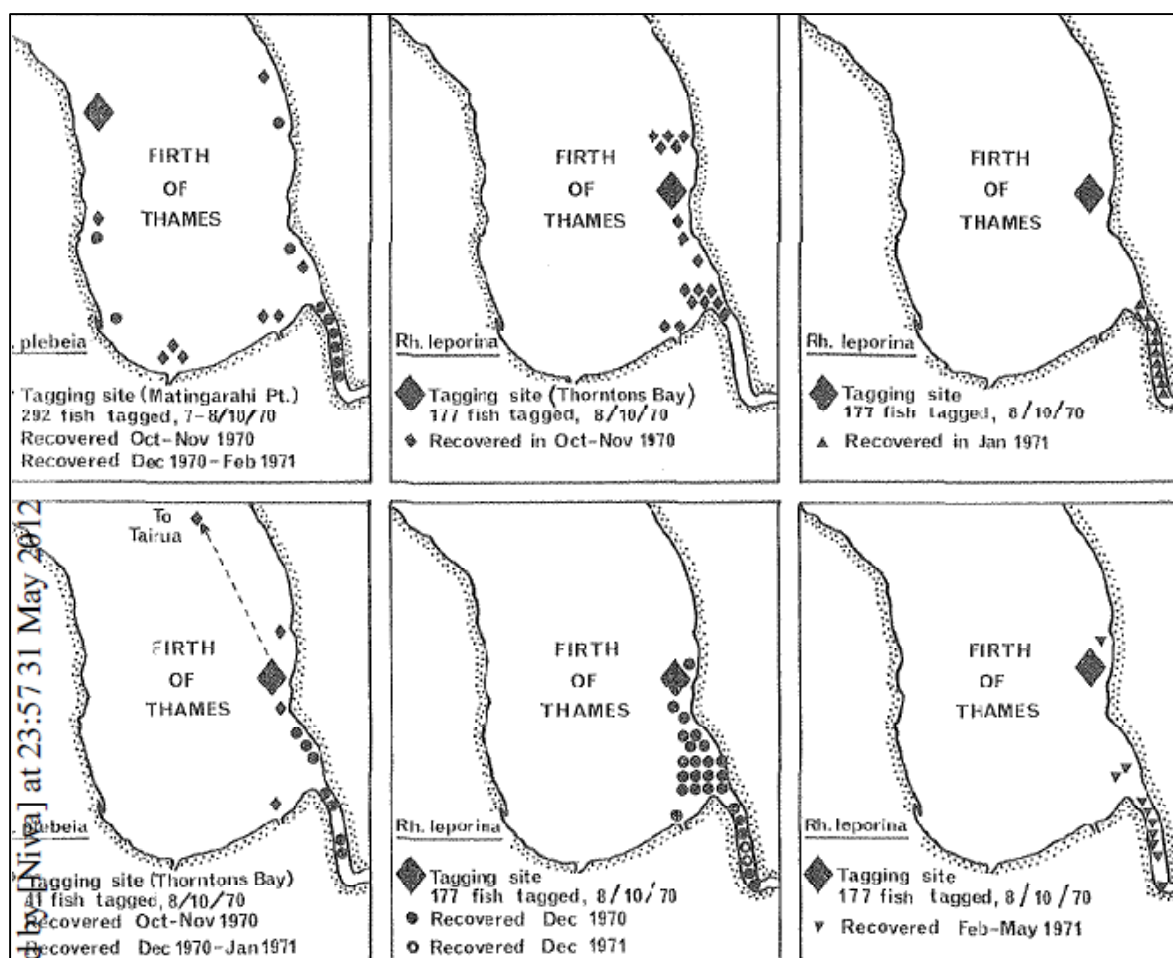


Figure 16: Tagging and recapture sites for sand flounder and yellow-belly flounder in the Hauraki Gulf (figure 5 of Colman 1974, reproduced with permission). Sand flounder are displayed on the two left hand maps; each representing tagged fish returns (the small diamonds) from a specific release site (the large diamond).

Population connectivity

Compared with sand flounder from many other New Zealand areas, Hauraki Gulf fish do not grow large (Colman 1972). Few sand flounders over 30 cm long were captured in the Hauraki Gulf, although in other waters, such as the east coast of the South Island, specimens over 40 cm long are common. This suggests different populations. Population differentiation in sand flounder was investigated by Colman (1976) using a meristic approach (e.g. counting fin rays sampled from fish around the country). Pooling of 40 spatial samples into 18 specific areas showed that there were considerable differences in mean number of fin rays between areas. Sand flounder stocks off the east and south of the South Island were clearly different from stocks in central New Zealand waters, and from those off the west coast of the South Island. Differences were also identified between west coast sand flounder and those in Tasman Bay, and for sand flounder on the east and west coasts of Auckland. The tagging studies detailed above also suggest localised populations with relatively limited movement. However, tagging studies mentioned in the sections above have shown that adult sand flounder do not move very far, which suggests that fish in fairly enclosed waters should be considered as separate stocks from those of their neighbours (Kirk 1988).

3.30 School shark (*Galeorhinus galeus*)

Fisheries catch:

Commercial: 3469 t¹

Recreational: 75–302 t^{1*}

Sexual maturity:

Females: 13–15 years / 130–140 cm^{2,3} Males: 12–17 years / 120–135 cm^{2,3}

Maximum age: at least 50 years / 170 cm³

Reproductive mode:

Aplacental viviparity

Gestation period: 12 months



Photo credit: M. Francis

¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; * Estimates of total recreational take were compiled across management areas for different years. See Plenary document for caveats around use of these data; ² Francis & Mulligan (1998); ³ Walker et al (2006).

School shark are found in cold to temperate waters in both the northern and southern hemisphere, including all round the New Zealand coast, mainly in depths of less than 200 m, and over most if not all the offshore rises and plateaus. The known depth range extends as deep as 800 m, and capture on tuna longlines in offshore waters over water depths of more than 1000 m indicates an oceanic occurrence (Bagley et al. 2000). School sharks are regularly caught in research trawl surveys, but most are juveniles, and it is probable that the large adults are not easily taken by trawl. West & Stevens (2001) reported that school shark make vertical ascents into the water column to the surface at night. The diet consists of both benthic and pelagic fish, cephalopods and also crustaceans, annelids and gastropods as juveniles (Olsen 1954).

Spawning

Like rig, this species commonly aggregates in inshore waters during warmer months and disperses across the shelf and upper slope during autumn and winter (Francis & Mace 1980). In his study of school shark in south-eastern Australia, Olsen (1954) reported that copulation was thought to occur offshore between May and July when running ripe males were reported, “*During this period good hauls from long line sets near the edge of the continental shelf are made by fishermen but subsequently the catches fall off with the dispersal of the sharks.*” It is likely that mating also occurs in deeper water in New Zealand; although Seabrook-Davison et al. (1985) noted that running ripe males were present in inshore waters from late October to March. Starr et al. (2010a, b) reported seasonal variation in the proportion of mature and immature males from voluntary logbook schemes, which suggested a greater number of mature males present in catches in a number of regions from summer through to early winter.

From studies carried out in Australia and Brazil (Olsen 1954, Peres & Vooren 1991) gestation is believed to be around 12 months with females probably breeding only every 2–3 years. Females are thought to move into shallow water in spring/summer months to give birth to live young although there are few reports of late term or recently pupped females in the New Zealand literature, apart from documentation of breeding females aggregating in the Kaipara harbour (M. Francis, unpublished). Australian studies have described embryos in various stages of development occurring from July to December with the latter being the main period of “*pupping*” (Olsen 1954). Litter sizes increase with

the size of the mother and range from 6–52 pups born at a length of around 30–35 cm (IUCN Red list).

Egg and larval transport

Not relevant as embryos are internally gestated, and juveniles born fully-formed.

Nursery habitats

Seabrook-Davison et al. (1985) described preferred pupping grounds as being along shallow (usually sandy) coastlines or in harbours and estuaries. Although well-defined nurseries have not been identified in New Zealand, juveniles up to 2 years old (less than 70 cm) are regularly caught in inshore trawl surveys, mainly along the west coasts of both the North (between Kaipara and New Plymouth) and South Islands, Golden and Tasman Bays, east coast of the South Island (Pegasus Bay, Canterbury Bight) and the Hauraki Gulf, but with some records from the Bay of Plenty, Hawke Bay to East Cape, the Kapiti coast, and Southland (Hurst et al. 2000a, Blackwell & Francis 2010). Smaller juveniles, (0+ and 1+) have been recorded from Kenepuru Sound (Marlborough), Lytleton, Akaroa harbours, Blueskin Bay, Manukau, Kaipara and Raglan harbours (M. Francis, unpublished). Although long thought to be an important nursery area, a recent set net survey found only 1+ school shark in selected areas of the Kaipara Harbour. Similarly, only older juvenile cohorts were caught in Golden Bay (2–4 year old) and Otago harbour (1–3 year olds) (Francis, M. et al. 2011). Small 0+ juveniles appear to be absent from the Southland region (SCH 5), Chatham Rise (SCH 4) and east Northland (SCH1) (Blackwell & Francis 2010, Hurst et al. 2000a).

In contrast to New Zealand, the biology of this species is relatively well studied in Australia. Olsen (1954, 1984) noted that females give birth mainly in November and December in protected bays and channels on low energy coastlines in Victoria and Tasmania. Well defined nursery areas, separate from the adults, were identified in these states; Port Sorell, Georges Bay and Pittwater in Tasmania, and Port Phillip Bay in Victoria. Recently born pups 30–38 cm were found in the upper limits of the marine environment in Port Sorrell, whilst larger sizes (70 cm) were found at the entrance to the estuary forming part of a wide bay. In Pittwater, larger juveniles ranged throughout the harbour whilst 0+ juveniles tended to aggregate in a deep, wide channel/gutter near the entrance, possibly to feed on fish retreating into deeper water as tide fell. Stevens & West (1997) resampled these nursery areas between 1991 and 1997 and found much lower catch rates and some sites where 0+ juveniles appeared to be absent. Additional sampling failed to find new nursery areas in Tasmania, Victoria, South Australia or Western Australia, but similar to New Zealand, 0+ juveniles have been caught in open coastal waters.

Adult habitats

Around the North Island, significant trawl survey catches only occur on the west coast between Northland and South Taranaki Bight, although catch rates were spatially patchy and included 1+ fish upwards (25–160 cm) (Langley 1994; Morrison & Parkinson 2000). On the east coast of the North Island, school shark were caught throughout the trawl survey area, mainly in depths greater than 50 m and north of Cape Kidnappers (Stevenson & Hanchet 2000b). Around the South Island, school shark are caught throughout the west coast survey area, with high catches north of Cape Foulwind between 100–200 m and mainly immature (under 90 cm) fish in Tasman and Golden Bay (Stevenson & Hanchet 2000b). Hurst et al. (1999) reported a patchy occurrence of school shark around Stewart Island with a size range of fish from 80 to 160 cm. The size of school shark caught in both the summer and winter trawl surveys along the east coast of the South Island were much smaller, with the summer catches including clear modes corresponding to new-borns (25–36 cm), 1+ (37–50 cm), 2+ and 3+ (66–80 cm), and few fish over 100 cm (Beentjes & Stevenson 2001). Catches were highest in

shallow waters during summer (around 30 m or less), and occurred in about 100 m depth in winter (Beentjes & Stevenson 2000). Highest commercial catches occur in the Southland region, where a set net fishery operates year round, as well as the west coasts of both islands and Cook Strait (Bradford 2001, Paul & Sanders 2001, Starr et al. 2010a, b)

School shark are mainly associated with the seabed, where they are more often caught on bottom longlines set over open ground, as opposed to foul areas (Paul & Sanders 2001). Fish often form small schools of the same size and sex. However, they are known to extend into the pelagic zone in offshore oceanic waters (Walker et al. 2006) where they have been caught on tuna longlines.

Adult migrations and movements

Movements of this species are complex and vary by size and sex. An opportunistic tagging programme underway since 1985 has tagged over 4500 school shark, with over 300 recaptures as of 2010 (Francis 2010). Most released school sharks would have been immature at the time of release. Around 80% of recaptures were within 5 years of release, with a maximum of up to 16 years at liberty. Just over half the returns were caught within the release QMA, the remainder were usually caught in an adjacent QMA but there were also some far longer journeys with 23% recaptured in Australia, one having travelled nearly 5000 km. From those recaptured after more than 5 years at liberty, many more fish had moved longer distances and females were much more likely to have travelled long distances than males (Hurst et al. 1999, Francis 2010). There was considerable interchange between the North and South Islands (Figure 17), with an apparent net northward movement with fish tagged in the Southland region moving northwards along both the east and west coasts, and many fish tagged off the central west coast of the South Island moving north and into Golden and Tasman Bays or reaching the North Taranaki Bight and beyond. There was also movement in the opposite direction, mainly moving from north of the South Island down to the Southland region. Hurst et al. (1999) suggested that if pupping was more prevalent in northern areas, this could explain the net northward movement. The authors also proposed that the prevalence of medium to large fish off Southland might indicate a feeding area utilized by those fish not pupping.

Movement to Australia was mainly by sharks tagged off the South Island. Tagging studies in Australia have also demonstrated mixing across the Tasman Sea, with journeys of up to 1260 km and some tagged animals remaining at liberty for more than 40 years (Olsen 1984, Brown et al. 2000). This level of movement strongly suggests that school shark form one stock within New Zealand with significant mixing with the Australian stock.

Population connectivity

See preceding section.

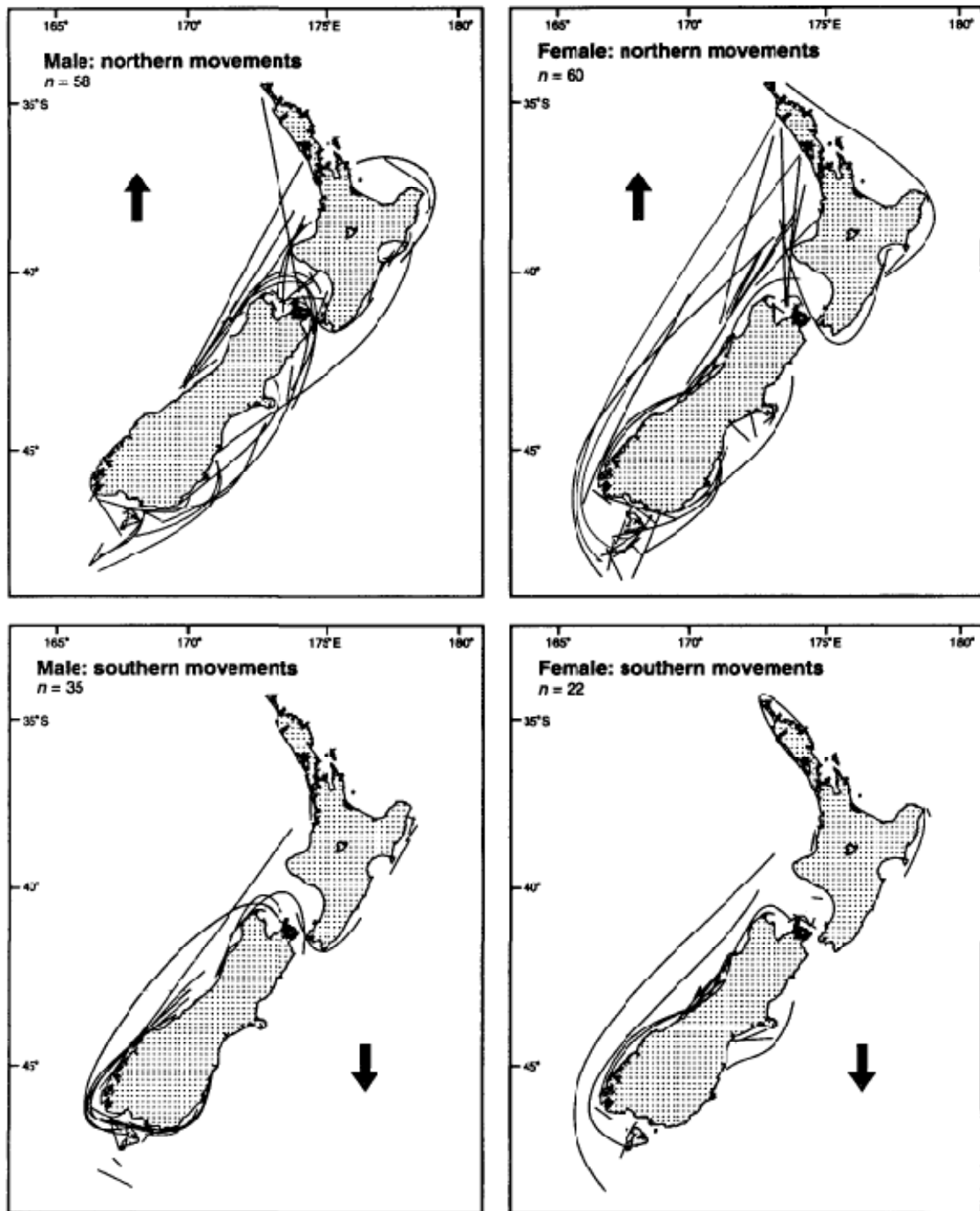


Figure 17: Movements of school sharks by sex, and by net movement, north or south around New Zealand (Source: figure 11 of Hurst et al. 1999, reproduced with permission).

3.31 Sea perch (*Helicolenus percoides* and *H. barathri* – note: species identities are unclear)

Fisheries catch:

Commercial: 1506 t¹

Recreational: 750 000 fish^{1*}

Sexual maturity: Females: 15–20 cm / 5 years²,
Males: 19–25 cm / 5–7 years²

Maximum age: 32–43 years / 45 cm²

Pelagic phase duration:

Eggs: no pelagic phase (lecithotrophic viviparous)

Larvae: Up to 52 days³



Photo credit: M. Francis

¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; *Numbers of fish only. Estimates were compiled across management areas for different years. See Plenary document for caveats around use of these data; ²Paul & Francis (2002); ³Furlani (1997).

Sea perch occur in both New Zealand and southern Australia. Two species have been identified in Australia using genetic markers; *H. percoides* occurring inshore and *H. barathri*, found further offshore, but similar in form and with overlapping ranges (Paxton & Colgan 1993). Genetic studies in New Zealand have been less conclusive (Smith 1998) and until recently it was assumed that only one species was present, *H. percoides*. However more recent work has indicated that four species of sea perch occur in the South-West Pacific, three of which could occur in New Zealand waters, *H. percoides*, *H. sp A*, and *H. barathri* (Smith et al. 2009). Bentley et al. (in press) supported this genetic hypothesis with evidence from depth distribution and catch rate data that these three species of *Helicolenus* could be found in New Zealand waters. The depth distribution of seaperch catch rates and catches suggested that these species are separated by depth and/or geography. Only *H. percoides* appears to occur in waters of less than 200 m in New Zealand, the area of interest for this review report. Bentley et al. stated that “*H. percoides* occurs in 0–250 m with a peak abundance around 150 m (based on analysis of catch rate by depth in this study and catch by depth from Haddon 2010). It occurs off eastern Australia, in the Tasman Sea and around New Zealand including Chatham Rise. There are two reasons to suspect that *H. percoides* extends as far west as the Chatham Rise and in particular Mernoo Bank. First, Smith et al (2009) found that one specimen collected from the Chatham Rise fell into the *H. percoides* branch (see their Figure 3). Second, there are some, albeit relatively minor, catches of seaperch on the Chatham Rise in depths less than 250 m. This is outside of the depth range of *H. sp A*, the other seaperch species found on the Chatham Rise (see below). Note however, that there is relatively little area of water less than 250m on the Chatham Rise, so the biomass there is likely to be small compared to other areas”.

Spawning

Sea perch are a lecithotrophic viviparous species, with egg fertilization and larval development occurring inside the female. Male gonads are thought to ripen earlier than females. Paul & Francis (2002) determined the maturity stage of over 700 fish during a survey off the east coast South Island in December–January and found that mature males were mainly recovering at this time of year, whilst mature females had full ripe gonads, many with eyed larvae. Graham (1956) observed ripe eggs and larval stages in females throughout much of the year apart from July and August, and suggested an extended spawning season for this species. In Australian waters, mating is reported to occur from June to August with a peak in fertilized ova occurring in spring (Park 1994).

Egg and larval transport

Larvae are extruded in a floating jelly-like mass once they reach about 1 mm in size. Graham (1956) observed an aquarium-held *H. percoides* extruding some 90 000 small larvae over a 30 minute period, whilst Mines (1975) reported a 30 cm (FL) female produced between 150 000 and 200 000 eggs during the breeding season, with between 40–50 000 fertilized and developing embryos. Once extruded, the jelly-like matrix dissolves to release the larvae. In New Zealand, larvae have been recorded from inner shelf waters off Otago from spring to autumn (Parsons 1999) whilst in Tasmania, *H. percoides* larvae were present in water samples from late winter through to late summer with no larvae caught between autumn and mid-winter (Furlani 1997). Larvae may remain in the water column for up to 52 days (Furlani 1997) before settlement on the seabed.

Nursery habitats

Little is known about settlement and habitat requirements of juvenile sea perch. Paul & Francis (2002) compared length frequency distributions from trawl surveys in different regions. Although confounded by the use of different vessels, cod end mesh size and depth ranges, they noted the presence of a slight mode between 13–15 cm in the summer survey series on the east coast of the South Island and similar small modes apparent in the Chatham Rise survey. Off the northeastern North Island, sampling across seasons indicated a small mode at 5–6 cm in summer. Small modes were also seen on the east coast North Island (17–19 cm) and west coast (12–15 cm).

Recent towed camera footage sampled small sea perch in abundance amongst tube worm beds in Pegasus Bay. This habitat may act as an important nursery habitat for this species, with Hurst et al. (2000a) reporting large catch rates for juveniles in this general area (up to 2.0 t km⁻²).

Adult habitats

Sea perch are a demersal fish found throughout New Zealand from less than 5 m water depth, to out on the continental shelf and slope, including the Challenger Plateau and Chatham Rise, down to 900 m, but not the Sub-Antarctic (McMillan et al. 2011). It is most common on the outer shelf and upper slope around the South Island, particularly off the east coast of the South Island and on the Chatham Rise (Anderson et al. 1998). Adults are caught in high numbers in trawl surveys in this region, particularly around 100 m depth (Beentjes & Stevenson 2001) and a large proportion of sea perch catch is taken as bycatch in trawl fisheries off this coast as well as on the Chatham Rise (Beentjes et al. 2007).

Sea perch inhabit a wide range of habitat types including shallow rocky reefs (Paulin & Roberts 1992) but also flat, open seabed. In the Fiordland region *H. percoides* is common in depths of less than 20 m (Francis & Ling 1985), where they are often found resting on rocky ledges. Elsewhere, they are found resting directly on the substrate, propped up by their pectoral fins. They are ambush predators, lunging at passing prey including small fish, crabs and shrimps.

Adult migrations and movements

No information is available.


Population connectivity

Very little data relevant to stock boundaries currently exists for this species. Being a benthic dwelling species, large scale movement of adults appears unlikely, although the generally smaller size of sea perch on the east coast of the South Island led Paul & Francis (2002) to suggest that larger fish may move into deeper water outside the range of the survey in that region (note: an alternative explanation

is that there are actually two species involved, as suggested by Bentley et al. (in press). Paul & Horn (2009) found clear between-sex differences in growth, and a strong indication of between-area differences, whilst Lawton et al. (2010) found evidence for discreet subpopulations inside four different fiords in Fiordland using adult morphology, length-at-age, d13C and d15N of muscle tissue, and trace elemental composition of whole otoliths as proxies for population isolation.

Trawl surveys on the Chatham Rise from 1992 show sea perch size to vary with depth and locality, possibly representing population differences as well as life history characteristics. Sea perch tend to be larger as depth increases (Beentjes et al. 2007). The work by Bentley et al. (in press), while based to some degree on circumstantial evidence, indicates that even if there are not biologically discrete species in New Zealand, the differences in depth preferences, maximum ages, growth rates and biomass trends observed suggests that there are at least biologically discrete stocks.

3.32 Silver warehou (*Seriolella punctata*)

<p>Fisheries catch: Commercial: 8004 t¹ Recreational: No recreational fishery</p> <p>Sexual maturity: 45 cm / 4–6 years²</p> <p>Maximum age: 23 years for females and 19 years for males²</p> <p>Pelagic phase duration: Eggs: 6 days³ Larvae: Unknown</p>	 <p>© NIWA P. Shearer</p>
<p>¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ²Horn & Sutton (1995, 1996); ³Grimes & Robertson (1981).</p>	

Silver warehou are a schooling species of Medusafish and are commonly found around the South Island (as far south as the Snares) and the Chatham Rise in water depths from 200 to 800 m. However, McDowall (1982) and Bruce et al. (2002) commented that *Seriolella punctata* may occur in shallow inshore waters, including bays, harbours and estuaries. Silver warehou have also been caught around the Auckland Islands, Bounty Islands and Pukaki Rise (Grimes & Robertson 1981). As well as occurring in New Zealand waters, silver warehou also occur in southern Australia (from South Australia to New South Wales and Tasmania), and Chile (FishBase 2012). Silver warehou aggregate to both feed and spawn, and adult silver warehou are pelagic invertebrate predators, feeding on free-floating colonial tunicates (Horn et al. 2011).

Spawning

Spawning silver warehou have been recorded in waters around New Zealand including: South Island west coast, Mernoo Bank – Chatham Rise, Chatham Islands and the North Island east coast (Hurst et al. 2000a). Spawning times from these different locations vary from late-winter through to early-summer (Livingston 1988). Investigation of silver warehou spawning in Australian waters led researchers to conclude that spawning was most likely spatially continuous between western Tasmania and southern New South Wales (Bruce et al. 2001b).

Egg and larval transport

Very little information is available.

Nursery habitats

Juvenile silver warehou have been reported over the continental shelf of the South Island, in particular on the Pegasus Bay shelf and the Canterbury Bight (Hurst et al. 2000a). Further, Annala et al. (1999) report that juvenile silver warehou inhabit shallow water (less than 200 m depth) and remain apart from sexually mature fish (which generally do not occur on the continental shelf, Hurst et al. (2000a)). Gavrilov & Markina (1979), via a feeding study of silver warehou, identified the progression of juveniles into the deeper waters of the continental slope with increasing size and changing prey distribution. They identified that young juveniles feed on plankton and then amphipoda and chaetognatha in coastal waters. This is consistent with Australian studies on this species, which have identified that adults occur over the outer shelf and slope to depths of 650 m (Gomon et al. 1994).

Adult habitats

See below.

Adult migrations and movements

During New Zealand's spring-summer, adult and juvenile fish migrate to feed along the continental slope off the east and southeast coast of the South Island (Annala et al. 1994). Silver warehou are thought to undertake a southerly migration following spawning on the Chatham Rise in spring (Paul 2000).

Population connectivity

Current understanding is that *"It is uncertain whether the same stock migrates from one area to another, spawning whenever conditions are appropriate, or if there are several separate stocks"* (MPI 2012).

3.33 Snapper (*Pagrus auratus*)

Fisheries catch:

Commercial: 6355 t¹

Recreational: ~3000 t^{1*}

Sexual maturity: 20–28 cm / 3–4 years²

Maximum age: >60 years (> 100 cm)³

Pelagic phase duration:

Eggs: 36 hours⁴

Larvae: 18–32 days⁵



Photo credit: M. Francis

¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ^{1*}Estimates of total recreational take were compiled across management areas for different years and using different survey methods. See Plenary document for caveats around use of these data; ²Francis & Pankhurst (1988); ³Francis (2001); ⁴Pankhurst (1991); ⁵Francis (1994).

Snapper are widely distributed throughout the warm temperate waters of New Zealand, Australia, Norfolk and Lord Howe Islands, the Philippines, Indonesia, China, Taiwan, and Japan (Paulin 1990). Within New Zealand, snapper are most abundant in the north half of the North Island (from Taranaki on the west coast to East Cape on the east coast) and in the north and west of the South Island. Snapper have been caught as far south as Otago (Graham 1939a). Snapper are a mostly demersal species, occupying water to 200 m, but are most common in water of less than 70 m depth. The diet of

snapper can be diverse, in response to local prey resources. Overall, crustaceans (mostly brachyuran and other crabs) are very important, with polychaetes, echinoderms, molluscs and teleosts forming the bulk of the remainder of snapper diet (Godfriaux 1969, 1974). Diet varies by size, with smaller fish feeding on small soft bodied animals (e.g. mysids and polychaetes), and the amount of larger and harder bodied organisms progressively increasing with size (e.g. fish, echinoids, hermit crabs, molluscs and brachyuran crabs) (Godfriaux 1969, Lowe 2013, Usmar 2012). Patterns in gut fullness suggest that snapper feed predominantly in the morning and evening (Godfriaux 1969), and there are also seasonal patterns in diet. Powell (1937) observed high proportions of pelagic items (e.g. salps and pelagic fish such as pilchards) within snapper diet during spring, suggesting that snapper were feeding in the water column at that time. In terms of the diet of juvenile snapper, it is very adaptable and can include a wide range of different taxa depending on what is available in the area occupied by an individual (Usmar 2009, 2012, Lowe 2013). There is clear evidence of both pelagic and benthic food sources being consumed, and comparisons across estuaries with different water turbidities, along with tank based experiments, suggest that suspended sediment loads fundamentally affect foraging strategies (Lowe 2013). Diet also appears to become more diverse as snapper become larger and their jaw morphology allows a wider range of diet items to be consumed (Usmar 2009). Overall, crustaceans are the most abundant item consumed, followed by molluscs, polychaetes and echinoderms. Ontogenetic shifts in diet also appear to occur, with snapper under 20 mm FL feeding predominantly on planktonic copepods, with diet becoming increasingly benthic as juvenile snapper grow larger than 20 mm (including benthic copepods, mysid and caridean shrimps, and polychaetes). For juvenile snapper of over 100 mm FL many harder bodied items are consumed, including brachyuran crabs, caridean shrimps, bivalves and hermit crabs as well as soft bodied polychaetes.

Spawning

Snapper are serial broadcast spawners with asynchronous ovary development (i.e., their ovaries contain multiple stages of development at one time). The spawning season for snapper extends from October to March, but peaks in November–December (Crossland 1977a, Scott et al. 1993). Spawning is initiated when water temperature reaches 14.8–16°C (Scott & Pankhurst 1992, Francis 1994). Spawning occurs between late morning and early evening (Scott et al. 1993, Zeldis & Francis 1998) and takes place on a daily basis for at least part of this extended spawning season (Crossland 1977b, Scott et al. 1993, Zeldis & Francis 1998). There is evidence, however, that not all individuals necessarily undertake spawning every year (Sim-Smith et al. 2012). In the Hauraki Gulf plankton, net tows have observed at least some snapper eggs in most locations during the spawning season, suggesting that some degree of spawning occurs around the coast (Cassie 1956, Zeldis & Francis 1998). The highest densities of snapper eggs, however, occur between Little and Great Barrier Island, from Coromandel Harbour to the top of the Firth of Thames and in an arc from the northern side of Waiheke Island to the Noises, Tiritiri Matangi and Kawau Islands (Zeldis & Francis 1998)(Figure 18).

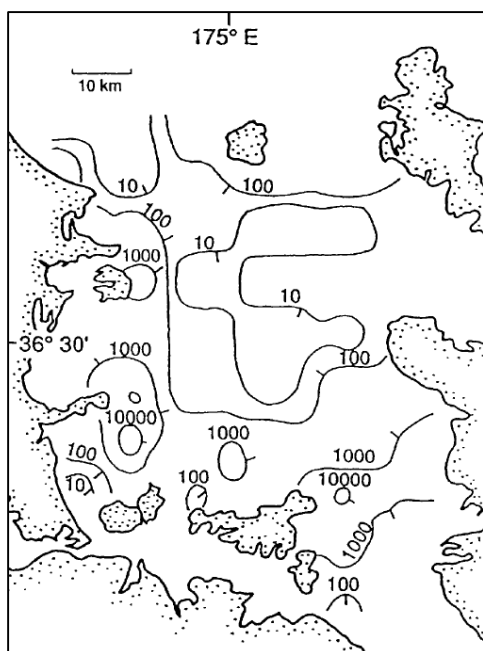


Figure 18: Snapper egg distributions in the Hauraki Gulf (no. per 125 m⁻³) 5–10 December, from a grid survey (Source: figure 3 of Zeldis 1993).

These spawning locations generally agree with the areas where high commercial bottom longline Catch Per Unit Effort (CPUE) is experienced in the Hauraki Gulf during spring (MPI unpubl. data). Beyond the Hauraki Gulf, other likely spawning locations include: Rangaunu and Doubtless Bay, the Bay of Islands, eastern Bay of Plenty, and the coastal areas adjacent to upper west coast North Island harbour mouths such as the Manukau and Kaipara harbours (Hurst et al. 2000a). Until the early 1980s significant spawning of snapper also used to occur in Tasman Bay at the top of the South Island. In spring, large schools of snapper used to gather near the water surface (presumably spawning); these were located by spotter planes that guided purse seine and surface trawl vessels to them (Parsons et al. 2009). Large catches were made from these surface schools for five years, until the schools could no longer be located. Similar schools of surface spawning snapper have been observed at Cockburn Sound in Western Australia (Wakefield 2010), but not elsewhere in New Zealand. This may imply that most snapper spawning in New Zealand occurs below (rather than at) the water surface. The only other observations of snapper spawning have been within tanks (Smith 1986, Vroegop 1997) and suggest that snapper move off the bottom in pairs or groups of courting individuals when spawning.

It is difficult to describe the spawning related movements of snapper without discussing the movement of adult snapper more generally. It has long been speculated that populations of snapper with different movement behaviours exist within the same geographic areas. The more mobile group of snapper are often termed ‘school fish’; *“Many fishermen believe that the school snapper is a distinct race of fish which enters the Gulf from outside waters for spawning purposes only. It is also claimed that, owing to their pelagic feeding habits, the school fish have sharper, less worn teeth than the bottom-feeding snapper usually resident in the Gulf”* (Cassie 1956). Later tagging studies conducted in the Hauraki Gulf (Crossland 1982) provided some evidence supporting the existence of a migratory ‘school fish’, as fish were observed to follow a southward migration in summer, followed by a northward movement of fish in winter. This pattern was complicated, however, by the movement of snapper in spring (from the western, southern and eastern shores of the Hauraki Gulf towards the periphery of the centre of the Hauraki Gulf). While Crossland (1982) concluded that aggregations of spawning fish within the Gulf were due to internal movements within the Hauraki Gulf, later tagging

studies (Gilbert & McKenzie 1999, Parsons et al. 2011, Morrison & Parsons, unpubl. data) suggested considerable exchange with the Bay of Plenty. In addition, acoustic and dart tagging of snapper from inshore locations (Hartill et al. 2003, Parsons et al. 2003, Egli & Babcock 2004, Parsons et al. 2009) suggested that residency is much more spatially discrete than previously documented (hundreds of metres, rather than 10–20 km) also occurred. Considering that these highly residential snapper remained within their home ranges during the spawning season, it seems unlikely that they migrated to the main spawning areas. During the spawning season some of these snapper also undertook small scale (hundreds of metres to 2 km) daily movements with associated depth oscillations that were not observed at other times of year (Parsons et al. 2003, Egli 2007). It is possible that these observations represent movement to localised aggregations of spawning fish.

For the other areas of New Zealand where snapper are present, tagging studies have also observed migration to specific spawning areas including to Tasman Bay and Pelorus Sound (Drummond & Mace 1984), and to the coastal areas adjacent to the mouths of the Kaipara and Manukau harbours (Walsh et al. 2006). In summary, spawning is an important driver of the movement patterns of snapper in New Zealand. Some snapper may move tens to hundreds of kilometres annually to partake in large spawning aggregations (e.g. movements from the Bay of Plenty into the Hauraki Gulf). Other snapper appear to move at a scale of tens of kilometres to partake in the same aggregations (e.g. within Hauraki Gulf scale). It is also likely that many smaller aggregations of spawning snapper occur around the coast, with the contributing individuals only moving hundreds of metres to a few kilometres to join aggregations.

Egg and larval transport

Post spawning, snapper eggs hatch after about 36 hours and first attempt to feed at 4–5 days post hatching (Pankhurst 1991). About 83% of snapper eggs perish before hatching, and a further 98% of snapper larvae are eliminated within the first 8 days after hatching (Zeldis et al. 2005). Snapper have an 18–32 day larval period (Francis 1994), where they occupy the middle of the water column with their horizontal distribution unaffected by the proximity of land (Kingsford 1988). Snapper larvae feed visually, probably on naupliar and copepodite copepods, cladocerans and bivalve larvae between 450 and 1100 μm (Zeldis et al. 2005). Water temperature appears to be very important to the early life stages of snapper. For example, snapper larvae spawned earlier in the season (and therefore into colder water) have a longer larval period, as it takes them longer to achieve the size required to metamorphose (Francis 1994). Furthermore, the abundance of 1+ year old snapper is positively affected by water temperature in the year of spawning (Francis 1993b). The strength and direction of wind and its effect on water column mixing and productivity (often associated with La Nina conditions that also have higher associated temperatures) is also important to snapper larval survival (Zeldis et al. 2005). When wind conditions are favourable, the higher productivity generated provides greater densities of food for snapper larvae, which ultimately results in greater survival to the juvenile stage (Zeldis et al. 2005).

Late stage snapper larvae are capable of sustaining swimming speeds of 15–20 cm s^{-1} (Clark et al. 2005) and appear to associate with the seabed as they approach settling (Trnski et al. 2005).

Juvenile habitats

The full distribution of snapper settlement habitats is not known, but immediate post settlement stage snapper (11–15 mm fork length (FL)) are common in shallow water estuaries and harbours between January and March (Paul 1976, Morrison & Carbines 2006, Usmar 2009, Lowe 2013, Morrison unpubl. data). In these estuarine habitats they are often associated with structured habitat types (Morrison et al. 2009, Morrison unpubl. data). Snapper of this size are rarely recorded in coastal

habitat types, however this may be an artefact due to the sampling methods utilised not having the resolution to detect snapper under 20 mm FL. For example, the trawl cod end mesh may be too large and the survey timing may not coincide with the period of settlement; towed camera systems do not detect snapper less than 5 cm (Morrison & Carbines 2006, Compton et al. 2012, Usmar 2012, Lowe 2013). Analysis of the chemical signatures within the otoliths of juvenile and adult snapper caught from a variety of habitats in the greater Hauraki Gulf, however, showed that nearly all individuals had a lower salinity portion at the centre of their otolith (Beumont et al., unpubl. data). This suggests that the majority of snapper probably occupy an estuary or harbour environment (where salinity will be lower) immediately after settling. While estuaries clearly appear to be important for early stage 0+ snapper, the absence of estuaries from SNA 2 (i.e. the lower half of the east coast of the North Island) (which is believed to be an entirely separate stock (Smith et al. 1978)) suggests that alternative settlement habitats may also be utilised (Walsh et al. 2012). Local ecological knowledge of fishers in Hawke Bay further support this, with reports of juvenile snapper being associated with the 'Wairoa Hard', a local shallow area of reefs and gravels.

The abundance of 0+ snapper within the shallowest parts of estuarine systems declines markedly after March (about 50–70 mm FL at this stage) (Usmar 2009, Morrison pers. obs., Parsons unpubl. data). At about the same time of year, 0+ snapper also start appearing in shallow coastal environments. For example, trawl surveys conducted with fine mesh liners within their cod ends (which may be more efficient at capturing 0+ snapper) observed the appearance of 0+ snapper of 50–100 mm FL from April–May in the shallow (5–20 m) water of the southwestern Hauraki Gulf (Paul 1976). In addition, towed video surveys also suggest that 0+ snapper (less than 80 mm FL) first appear in the southern Hauraki Gulf in autumn (Compton et al. 2012). However, juveniles may also stay in estuarine environments for at least the first 18 months of life, with data from Mahurangi Harbour showing them to move into the deeper parts of the harbour in the colder months (but see Usmar 2009), while numerous larger juveniles of over a year old are also present in the Kaipara Harbour (Francis et al. 2012, Morrison et al. unpubl. data). The relative contributions of estuarine versus more coastal habitats is currently unknown, apart from on the west coast North Island (see below).

After appearing in coastal environments as late stage 0+ individuals (either from settlement, or through post-settlement movement), juvenile snapper gradually disperse with age (Paul 1976). Seasonal trends in abundance suggest that an inshore (summer) versus offshore (winter) movement of juvenile snapper may occur (Paul 1976, Francis 1995). Overall, however, juvenile snapper are more abundant at inshore locations (Blackwell & Stevenson 1997, Morrison 1997, 1998, Morrison & Francis 1997). These direct observations of juvenile snapper distribution patterns generally agree with inferences on snapper dispersal acquired from chemical markers within snapper otoliths. These chemical markers suggest that adult snapper over a wide spatial range (up to hundreds of kilometres) are composed of individuals that originally occupied a small sub-set of the total available nursery habitats (estuaries/harbours) within that range (Hamer et al. 2011, Morrison unpubl. data). For the New Zealand example, the majority of snapper within the west coast North Island population (SNA 8) had originally inhabited the Kaipara Harbour as small juveniles (Morrison et al. 2009). This result illustrates two important aspects of snapper life history: (1) it is likely that a few critical estuarine nursery locations, with important structured habitats such as (sub-tidal) seagrass, have a disproportionate importance to the maintenance of snapper populations overall, and (2) considering what we know about the movement of adult snapper (generally resident to an area of tens of kilometres or less), the largest scales of dispersal (up to hundreds of kilometres) are likely to occur at an early juvenile stage.

Known areas of high value nursery habitats include the very extensive sub-tidal seagrass meadows of the Kaipara Harbour (west coast North Island), the Parengarenga and Rangaunu harbours (east Northland), and what sub-tidal seagrass remains in Tauranga Harbour. Horse mussel beds have also been shown to support higher densities than surrounding bare sediment areas (Morrison et al. 2009, Usmar 2009). Extensive subtidal seagrass areas in Whangarei Harbour which were eliminated in the 1960s (Morrison 2003) also appear to be recovering, and are also likely to provide increasingly substantial numbers of juvenile snapper to the lower East Northland region.

In terms of the specific habitat associations of juvenile snapper, 0+ snapper often utilise structured habitat types. For example, in Rangaunu Harbour in East Northland, 0+ snapper can be found at extremely high densities over shallow seagrass beds (more than 160 per 100 m², Morrison unpubl. data). 0+ snapper also occupy other types of structure, such as horse mussel and sponge habitats (Usmar 2009, Compton et al. 2012). Due to the increasing dispersal of juvenile snapper during their first year, however, 1+ snapper expand out their distribution to occupy a broad range of habitats. Francis (1995) observed that certain coastal locations consistently had high abundances. These locations were typified by muddy (rather than muddy sand) bottom types, and juvenile snapper from these locations also had greater body condition (Francis 1997d). In Japan, the availability of food also appeared to be an important driver of juvenile snapper habitat preference (Azeta et al. 1980, Kiso 1982, Sudo et al. 1983). Subsequent research conducted in the same region as Francis' (1995) study, however, suggested that the abundance of 1+ and 2+ snapper was strongly influenced by complex habitat structure when assessed at a finer spatial scale (Thrush et al. 2002). Later research conducted in the southern Hauraki Gulf also suggested that 0+ and 1+ snapper were associated with benthic habitat structure and areas of low orbital velocity (Compton et al. 2012). In contrast, larger snapper (3+ and older) were associated with areas of high benthic diversity and high tidal current velocities (Compton et al. 2012). In addition to occupying soft sediment habitat types, juvenile snapper are also common within rocky reef habitats (Kingett & Choat 1981, Ross et al. 2007). While the snapper observed in these studies were referred to as 0+ individuals, it is more likely that they were actually 1+ individual's (fish were observed in February–March and were about 100 mm FL, a 0+ snapper should be about 50 mm FL at that time of year (Francis 1994)). This is an important distinction because it excludes rocky reefs as direct settlement habitats. Within the rocky reef habitat, the juvenile snapper observed displayed preferences for specific habitat components. Kingett & Choat (1981) observed the highest densities of snapper over coralline turf habitat, but no relationship with habitat complexity. Experimental manipulations suggested that these areas of coralline turf were important for feeding of juvenile snapper. Ross et al. (2007) observed snapper to be most abundant on areas of sediment immediately adjacent to the edge of the rocky reef and experimental manipulation in tanks suggested that predators encouraged the use of structured habitat. It is possible that there are early stage relatively extensive movements being made from initial settlement habitats, of which we are currently unaware.

Adult habitats

Adult snapper occupy nearly all habitats (sand, mud and rock) in nearly all locations (from estuaries to the open coast) within their overall distribution range (Crossland 1981b). Adult snapper (4+ and greater) occupy nearly all habitat types in less than 150 m of water in northern New Zealand. However, while trawl surveys have shown that shallow inshore areas (less than 50 m) are very important to adult snapper (Kendrick & Francis 2002), this result may be influenced by gear selectivity (gear being less effective for larger snapper) and survey timing (mostly in spring when many snapper move inshore for spawning purposes). Furthermore, when the distribution of snapper is assessed by size, larger fish appear to be more abundant further from shore (B. Hartill, unpubl. data).

It is difficult to describe the distribution and habitat associations of adult snapper without making reference to the pervasive movement of snapper across different locations.

Adult migrations and movements

Seasonal patterns of abundance imply that a portion of the snapper population moves in and out of inshore waters such as the Hauraki Gulf (Figure 19), potentially in relation to spawning (Cassie 1956, Crossland 1982, Millar et al. 1997, Willis et al. 2003, Compton et al. 2012, Ministry for Primary Industries unpubl. data). Other evidence strongly points to residence, at least at the scale of tens of kilometres (Crossland 1982, Gilbert & McKenzie 1999, Walsh et al. 2006, Parsons et al. 2011), if not at a scale of hundreds of metres (Willis et al. 2001, Hartill et al. 2003, Parsons et al. 2010, 2011). Generalisations about snapper movement are clearly difficult. A tagging programme designed to address this and other issues contrasted the movement patterns of snapper from different locations and habitat types within the Hauraki Gulf (Parsons et al. 2011, Morrison & Parsons unpubl. data). Snapper tagged in soft sediment habitats of around 30 m depth were the most mobile, moving 19 km on average. Alternatively, snapper tagged in shallower soft sediment or reef habitats were much more resident, (average distance moved 3.6 and 0.7 km respectively). Furthermore, very few of the snapper tagged on reefs were caught outside of the reef on which they were tagged, despite heavy fishing pressure occurring throughout the Hauraki Gulf and the long duration of the recovery phase (over two years in Parsons et al. 2011, three further years subsequently as of summer 2012/13). Other studies have however suggested that some portion of the snapper population on reefs moves to deeper water in winter (Willis et al. 2003), based on baited camera visual counts. However, an alternative explanation is that baited cameras may underestimate relative abundance at colder times of year, when snapper have a lower metabolic demand for food. A potentially similar situation occurs where recreational fishers catch relatively few juveniles in winter and assume that they move elsewhere, but towed camera work shows them to be present throughout the year (Usmar 2009, Compton et al. 2012).

Given the relatively low numbers of small juvenile snapper observed on coastal reef systems, and the residency shown from tagged fish returns, immigration of adults/sub-adults onto reefs and a subsequent behavioural change to residency is likely. While evidence regarding potential behavioural shifts is sparse, Denny et al. (2004) observed a dramatic recovery of large adult snapper (about 40 cm FL) in the first year of full protection at the Poor Knights Marine Reserve. These fish were too large (and therefore old) to have settled directly into the reserve and grown through from the juvenile stage in that short time period, and must have actively immigrated in from elsewhere, followed by taking up resident behaviour – strongly implying that adults can recruit to new locations via changes in movement behaviour.

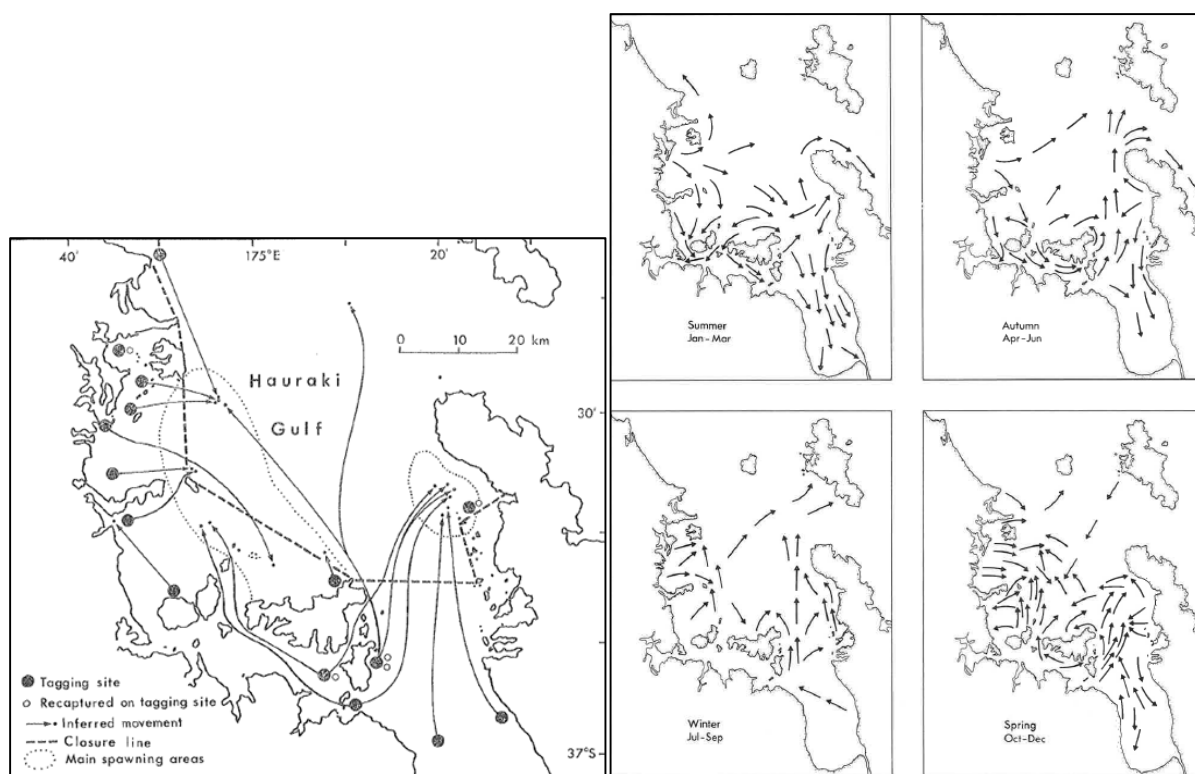



Figure 19: Movements of snapper tagged in the Hauraki Gulf and recaptured September – December 1974.. Patterns of inferred movement of tagged snapper in the Hauraki Gulf. Source: figure 6 of Crossland 1982, reproduced with permission.

Population connectivity

There are most probably several separate snapper stocks around New Zealand. For example, snapper on the west coast of the North Island (SNA 8) are separate from snapper on the east coast (SNA 1), although some genetic mixing is likely to occur at Ninety Mile Beach (Smith et al. 1978). Within the SNA 1 stock, differences in growth rate and relative year class strength suggest that east Northland, the Hauraki Gulf and the Bay of Plenty are separate sub-stocks, despite significant movement between the Hauraki Gulf and Bay of Plenty (Gilbert & McKenzie 1999). Considerable mixing also probably occurs between the Bay of Plenty and snapper from south of East Cape (SNA 2). Snapper from within Hawke Bay (also SNA 2), however, are genetically distinct (Smith et al. 1978) and have much faster growth rates than snapper from the northern parts of SNA 2 (Walsh et al. 2012). Snapper from the northern South Island (SNA 7), also have their own unique pattern of year class strengths and very fast growth rates, suggesting a distinct stock exists within SNA 7. Where separate stocks exist, this logically implies that recruitment processes, and all the necessary conditions and habitats, must largely exist independently of other stocks. While SNA 8 and 1 have received research attention on juvenile stages, within SNA 2 and 7 juvenile snapper are rarely observed and their habitat associations are unknown (Paul & Tarring 1980, Blackwell & Gilbert 2006, Walsh et al. 2012). However, the 2009 trawl survey of Tasman and Golden Bays caught more snapper than on any previous survey, including over 150 juveniles in the 14–19 cm size range (2+). As most snapper tend to leave the Tasman and Golden Bays by the time of the survey, it has been suggested that this result indicates the presence of a strong year class (Stevenson & Hanchet 2010).

3.34 Spiny dogfish (*Squalus acanthias*)

<p>Fisheries catch: Commercial: 6026 t ¹ Recreational: 234 t / <10% of total catch ¹</p> <p>Sexual maturity: Females: 10 years / 73 cm ^{2, 3}, Males: 6 years / 58 cm ^{2, 3}</p> <p>Maximum age: Females: 26 years / 111 cm ², Males: 21 years / 90 cm ²</p> <p>Reproductive mode: Aplacental viviparity</p> <p>Gestation period: 24 months ⁴</p>	
<p>¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ²Hanchet (1986); ³Hanchet (1988); ⁴Ford (1921).</p>	

With a worldwide distribution in temperate waters, spiny dogfish are found mainly around the South Island of New Zealand, but reach as far north as Cape Maria Van Diemen on the west coast, and the East Cape on the east coast of the North Island, from the intertidal down to 900 m. They are also present on the Campbell and Bounty Plateaus and the Chatham Rise. Observer longline reports of spiny dogfish caught up to 100 km offshore between Jackson Bay and Snares Island, and in trawl surveys in depths greater than 1000 m suggest that these species also occur pelagically, although their range is unknown. Diet consists of a wide variety of both benthic and pelagic prey, dominated by crustaceans, fish, salps and molluscs, and varies with size, sex and season (Hanchet 1991). The prey of smaller individuals is more planktonic, whilst larger individuals feed increasingly on fish and benthic organisms, especially in winter (Alonsoa et al. 2002, Hanchet 1991). Hanchet (1991) also found evidence of cannibalism on juvenile spiny dogfish by adults, but noted that this could also be evidence of scavenging behaviour on fish discarded by fishing boats or taken from nets.

Spawning

Using samples collected from trawl surveys off the east coast of the South Island from Kaikoura to Foveaux Strait, Hanchet (1986, 1988) found that parturition, mating, and ovulation all appeared to occur offshore in deeper waters near the edge of the continental shelf, between April and September. Females carrying full-term embryos, recently-pupped and with newly ovulated eggs were found in deep water during winter. In males, the variation in proportions of ampullae containing each spermatogenic stage suggested that they move offshore to mate between May and August. Once embryos reach around 2 cm in length, females move inshore to warmer waters (less than 50 m depth) and remain for around 9 months, by which time embryos reach an average size of 11 cm. By the following summer, the pregnant females are thought to move back offshore with parturition occurring in autumn after a gestation period of nearly 24 months. Graham (1956) reported that parturition may also occur in Blueskin Bay, having found “*young specimens, evidently born only a short time ago*” and citing reports of females caught with young around 11 inches with yolk sacs fully absorbed. Both offshore (Bigelow & Schroeder 1953) and inshore (Templeman 1944, Holden 1967) pupping have been reported for this species elsewhere in its distribution, whilst Ketchen (1972) suggested that parturition may occur in mid water, and Stenberg (2005) reported that mature females tended to stay in mid water and move to shallow water to give birth. Hanchet (1988) noted that midwater parturition may account for the low numbers of post-partum females caught in the breeding season of his New

Zealand study. The lack of maturity stage data for this species in the trawl survey database means that Graham's observations and Hanchet's study remain the only information on possible pupping and mating areas for this species in New Zealand.

Egg and larval transport

Not relevant.

Nursery habitats

If pupping does occur offshore, juveniles must move inshore relatively soon after. Born at a size of between 18–30 cm in length, young of the year (under 45 cm) are found in shallow water (mainly less than 20 m but as deep as 60 m) along the east coast of the South Island from Banks to the Otago Peninsula (Graham 1939b, 1956; Hanchet 1986). Hurst et al. (2000a) reported catch rates of up to 26.2 t km⁻² from the *Kaharoa* inshore trawl survey along this coast indicating its importance as a nursery ground for this species. Juveniles are also found in lower abundances off the west coast of both islands between North Cape and Jacksons Bay (including Cook Strait) and Southland and on the Chatham Rise. They are rare on the Stewart-Snares shelf and the central Campbell Plateau (Hanchet & Ingerson 1997). The abundance in depths less than 200 m on the Chatham Rise is not well known, but they do occur between 200 and 400 m. Graham (1956) reported that juveniles remain in the harbour for some time before moving into deeper water. Older juveniles move gradually deeper as they grow and are found as deep as 600 m, usually occurring in size-segregated schools often with mature males and sub-adult females (Hanchet 1986). New Zealand *S. acanthias* mature at a shorter length than fish from the North Atlantic and North Pacific.

Adult habitats

On the inshore trawl surveys, spiny dogfish are often the most abundant species by weight on the west coast South Island survey, accounting for 25% of the catch in 2009, with juveniles (less than 50 cm) regularly caught (Stevenson & Hanchet 2010). On the ECSI survey, they are caught in over 90% of stations, with highest numbers in the inshore strata in the Canterbury Bight (10–30 m) (Beentjes & Stevenson 2000). The discontinued summer series also caught fish between 20 and 40 cm, most likely representing recently born pups (Beentjes & Stevenson 2001). Along this coast, fish are smaller than those from the Chatham Rise, Southland, and the sub-Antarctic surveys and more males than females are caught (Bagley & Hurst 1996, O'Driscoll & Bagley 2001). In the waters off southern New Zealand, Jacob et al. (1998) listed spiny dogfish as one of the dominant species in the shallow water assemblage and this species supports one of the largest inshore commercial fisheries in terms of tonnage landed. Spiny dogfish were found to be more abundant on dredged compared to undredged sites in Foveaux Strait, particularly in autumn (Carbines & Cole 2009).

Similar to other elasmobranchs, habitat use in spiny dogfish is strongly dependent on water temperature conditions with clear water temperature preferences for between 6 and 15° C (Shepherd et al. 2002, Compagno et al. 2005). Shepherd et al. (2002) found both length- and sex-specific associations with hydrographic variables including temperature and salinity in the Bay of Fundy, suggesting preferences for particular water masses. Seasonal movements, both onshore-offshore and along shore, triggered by changes in temperature have also been documented in both Atlantic and Pacific populations (Hisaw & Albert 1947, Holden 1967, Stenberg 2005, Campana et al. 2007) and in New Zealand (Manning et al. 2004, 2009). Like many elasmobranchs, spiny dogfish are highly segregated by both size and sex and segregation is linked to depth (Templeman 1944, Bigelow & Schroeder 1953, Rago et al. 1994). Aside from temperature and depth, there are few direct studies that assess benthic habitat associations for this species, although Methratta & Link (2007) noted a weak

association with coarser substrates in their study of ontogenetic variation in habitat association in the Gulf of Maine.

Adult migrations and movements

Once maturity is reached, between 6–10 years of age, fish undertake inshore / offshore migrations associated with sexual reproduction. In addition to these movements, a north / south migration along the east coast of the South Island during autumn / spring was proposed by Hanchet (1986), who analysed data from historical surveys from the area (W.J. Scott and James Cook) carried out from 1978 to 1983. Spiny dogfish were abundant in the Canterbury Bight during winter and as water temperatures increased they moved either offshore, or southwards towards Nugget Point. Although it is not known whether fish migrate further south, *W.J. Scott* surveys of the Stewart–Snares shelf during the late 1970s showed a large increase in catch rates of spiny dogfish from October–December through to January–April (Fenaughty & O'Sullivan 1978). Manning et al. (2004, 2009) noted seasonal patterns in commercial catches along the east coast of the South Island and around the southern plateaus, with about half of the total catch from SPD 3 being caught from January to May, and 71% of the total catch in SPD 5 caught during December to April. These variations in catches at certain times of the year are likely to reflect seasonal movements either onshore-offshore and / alongshore, relating to reproduction. Seasonal changes in catch rates on *W.J. Scott* surveys on the west coast of the South Island (June 1981 and April 1983) were also thought to reflect a potential northwards movement of spiny dogfish up to the South Taranaki Bight, and Tasman and Golden Bays (Hurst & Fenaughty 1985, Hanchet & Ingerson 1997). However, as well as these seasonal changes in abundance, resident populations of spiny dogfish are also present in the North and South Taranaki Bight and the Stewart/Snares Shelf. Hanchet & Ingerson (1997) concluded that the changes were not necessarily consistent with clear seasonal migrations between areas and that more information was needed. To date, insufficient tagging has taken place to assess individual rates of movement for the New Zealand population.

Population connectivity

Elsewhere in its range, considerable information has been collected on the biology, movements and genetics indicating that two genetically distinct groups of spiny dogfish exist (Franks 2006, Verissimo et al. 2011), which correspond to different life-history characteristics. In the North Pacific, spiny dogfish attain a greater maximum size and later age at first maturity compared to South Pacific and Atlantic populations, where the lack of genetic difference indicates some level of gene flow across large distances. A number of tagging studies in these regions have shown long-distance movements including trans-oceanic migrations, as well as seasonal along shore and onshore / offshore movements (Holden 1967, Templeman 1976). In the Northeast Pacific, dogfish tagged inshore demonstrated site fidelity whilst those tagged offshore travelled greater distances (McFarlane & King 2003). Thus spiny dogfish show great variation in movement patterns and it seems possible that both resident and migratory populations could exist in New Zealand.

3.35 Tarakihi (*Nemadactylus macropterus*)

Fisheries catch:

Commercial: 5708 t ¹

Recreational: 300–800 t ^{1*}

Sexual maturity: 4–6 years / 25–35 cm ²

Maximum age: 30+ years / 71 cm ^{3,4}

Pelagic phase duration:

Eggs: Unknown

Larvae: 7–12 months⁵ (paper fish phase)



Photo credit: M. Francis, NIWA

¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; *Estimates of total recreational take were compiled across management areas for different years and using different survey methods. See Plenary document for caveats around use of these data; ²Tong & Vooren (1972); ³Graham (1956); ⁴Vooren (1977); ⁵Vooren (1972).

Tarakihi are caught in coastal waters down to 400 m all around New Zealand from Cape Reinga to the Snares Islands, as well as shallower areas of the Chatham Rise and Chatham Islands (Anderson et al. 1998, McMillan et al. 2011). They are also found along Southern Australia including Tasmania, and probably also off South America. Tarakihi are regularly caught in the inshore trawl surveys, depending on the depths range covered, being most abundant at depths greater than 100 m. The major commercial fishing grounds for tarakihi are west and east Northland, the western Bay of Plenty to Cape Turnagain, Cook Strait to Canterbury Bight and Jackson head to Cape Foulwind. Tarakihi feed on a wide range of small benthic invertebrates including polychaetes, crustaceans, echinoderms and molluscs by non-selective ingestion of bottom sediments (Godfriaux 1974). Feeding intensity is highest at night (Paul 2000).

Spawning

Tarakihi are serial spawners, aggregating in a number of areas around New Zealand in summer-autumn with final maturation and ripening of gonads related to a drop in seawater temperature at this time of year (Tong & Vooren 1972). In the North Island, the western Bay of Plenty, East Cape area, between Lottin Point and Hicks Bay and south of East Cape towards Mahia Peninsula are known spawning grounds (Figure 20). Monthly samples of adult fish from Motiti Island in the Bay of Plenty showed a rapid increase in gonad weight as fish matured in March, with running ripe gonads appearing in April, dominating in May and reducing in frequency in June (Tong & Vooren 1972). Fish aged from these samples indicated that older fish (over 6 years) were more abundant in autumn near Motiti Island than other times. Samples taken at the same time from Lottin Point (between East Cape and Cape Runaway) showed that fish with mature gonads started to appear slightly earlier, in February (Tong & Vooren 1972) and ripe, running ripe and spent fish (up to 20%) have also been recorded between February and April along the south-east coast of the North Island (FMA 2) (Hurst et al. 2000a).

On the west coast of the North Island, Reid (1969) described the commercial fishery off Auckland that developed after 1952 when some vessels started fishing out of Onehunga. Fishers located and targeted a “tarakihi run” of schooling fish between 36° 30'S and 37° 30' N. Fish were abundant at around 100 m depth during March, April and May, with highest catches at night. Although information on gonad state was not reported, it seems likely that the fishery had located a spawning aggregation and Vooren (1975) suggested that this may stock an “occasional” nursery ground

identified inshore on the North Taranaki Bight. There are few trawl database records of ripe and running ripe fish or of 0+ or 1+ fish along this coast, although the timing of the inshore trawl research surveys has likely been too early to sample the spawning, being in spring / summer. Further south, along the Manawatu coast, Vooren (1975) reported that small tarakihi were regularly recorded in commercial catch samples and in a handful of research trawl stations in 50–60 m depth.

The northeast coast of the South Island is another historically well-documented spawning ground with spawning fish reported from northern Pegasus Bay, including Conway Ridge and Cape Campbell; from January–February onwards (Tong & Vooren 1972, Fenaughty & Bagley 1981). Robertson (1978) found tarakihi eggs at the edge of the shelf from Kaikoura to Cook Strait, most abundant off Point Gibson (south of Kaikoura) in January and over Conway Ridge in February and March. Highest densities were found in waters characteristic of the Southland Current in terms of temperature and salinity. The earlier timing of the spawning activity was thought to be due to the earlier drop in water temperatures at this more southerly location.

Peak catches in the target commercial fishery in TAR 7 along the west coast of the South Island (and Cook Strait) coincide with the summer-autumn spawning season, and are most likely spawning aggregations (Manning et al. 2008). Ripe and running ripe fish are caught all along the west coast of the South Island between Jackson Bay northwards to Cape Foulwind and Robertson (1978) reported tarakihi eggs at least from the sounds of Fiordland (Milford and Dusky Sounds), and speculated that they occur northwards along the west coast.



Figure 20: Areas of occurrence of eggs of tarakihi in New Zealand waters (Source: figure 7 of Vooren 1975, reproduced with permission).

Egg and larval transport

Recently spawned eggs have been collected in surface waters between Cape Runaway and Mahia Peninsula in March and April (McKenzie 1961, Robertson 1978). Highest densities were found inshore, especially around East Cape. Robertson (1978) also estimated the ascent rate of eggs and determined that spawning occurred off the bottom in mid water, and appeared to be most intense between 1600 and 2000 h, falling off through the night. Robertson (1973) proposed that the cooling

subantarctic surface water inhibited spawning south of Banks Peninsula and found no evidence of tarakihi eggs in three consecutive years of sampling, although Graham (1939b) did report specimens with ripe roes from North Reef, Otago in December, and Parsons (1999) found one larva in samples from this region in April.

Tarakihi are unusual in that the pelagic larval and postlarval stages spend 9–10 months drifting in offshore waters (Bruce et al. 2001a) before metamorphosing into juveniles and settling at around 7–9 cm (Vooren 1972). This extended larval phase allows for spawning and nursery grounds to be spatially separated and this appears to be the case, with significant commercial fisheries catch around the northern North Island but little evidence of local spawning areas, other than the eastern Bay of Plenty and East Cape area and possibly the west coast of the North Island; and no known well defined nursery area. The links between adult and juvenile habitats will depend on the prevailing water currents, but the relatively larger size of settling juveniles could allow for active selection of particular habitats. Studies of a nursery area in Tasmania noted the lack of consistent onshore flow of surface waters during spring in the area and suggested that active horizontal swimming must play a role in the movement of settlement (Jordan 2001). Post larvae sampled in shallow waters off Otago and Canterbury in late spring/early summer were thought to have been spawned in southern Fiordland the previous year, after 7–10 months drifting in the Southland Current (Robertson 1978). This lower west coast South Island spawning area is also the most likely source of Tasman Bay juveniles, transported north by the Westland and D’Urville currents (Vooren 1972).

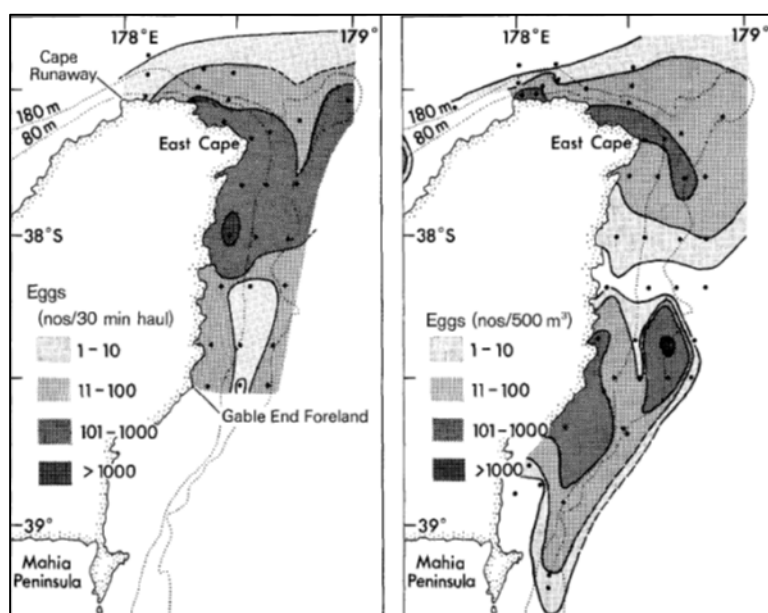


Figure 21: Distribution of tarakihi eggs at the sea surface from the East Cape area, left 26– 29 March 1971, right 6–13 April 1972. Source: figure 3 of Robertson 1973.

Nursery habitats

Despite the significant spawning activity off East Cape, a defined nursery ground has not been located in the Bay of Plenty or along the south-eastern coast. During their trawling surveys across all seasons, Tong & Elder (1968) found only a few fish less than 25 cm, caught mainly between 100–200 m in winter. Later sampling efforts included trawl and line fishing targeting foul ground, but again small fish were largely absent (Tong & Vooren 1972). Vooren (1975) noted the eastern Bay of Plenty, East Cape and Hawke Bay as areas where tarakihi under 20 cm were “occasionally recorded” from commercial catches through the historical Catch Sampling Programme. Further south off Castlepoint,

fish as small as 12 cm were recorded and fish under 20 cm were “regularly recorded” from this area. More recent data from the Bay of Plenty *Kaharoa* surveys caught fish mainly between 25–40 cm (Morrison et al. 2001b) although some trawl stations produced catch rates of 0.25 t km⁻² of juveniles (Hurst et al. 2000a). Along the south-eastern coast, a small mode around 20 cm was present in some years, with a maximum catch rate of 0.1 t km⁻² off East Cape (Stevenson & Hanchet 2000a, Hurst et al. 2000a).

Despite the apparent lack of spawning activity off the lower South Island, juvenile (under 20 cm) tarakihi are found as far south as coastal waters of Stewart Island (Hurst et al. 2000a), all along the east coast, including Otago harbour (Graham 1956), and as far as Cape Campbell, with small fish especially abundant in Pegasus Bay and Canterbury Bight, where one tow recorded a catch rate of 4.9 t km⁻² (Fenaughty & Bagley 1981, Hurst et al. 2000a). Up to three length modes are apparent in the east coast South Island winter trawl surveys representing 0+ (13 cm) and 1+ (18 cm), and a larger mode at around 26 cm, with highest catches of small fish in the Canterbury Bight between 30 and 100 m (Beentjes & Stevenson 2000, 2008, 2009, Beentjes et al. 2010a). Vooren (1975) also noted that the four youngest size classes form distinct length frequency modes on the nursery grounds and commented that along this coast juvenile tarakihi were often associated with “*a rich invertebrate benthic epifauna containing sponges, worms, echinoderms and molluscs*”, citing the rich sponge habitat locally called the “*Hay Paddock*” off Oamaru (recently identified as extensive sponge assemblages on soft sediments, Jones & Morrison, unpubl. data).

Juveniles are found in the west coast South Island trawl survey along the west coast, but with the highest abundances in Golden and Tasman Bays. In his description of tarakihi nursery grounds, Vooren (1975) analysed both survey and commercial data from the region and found highest densities of juveniles up to 26 cm long (including fish up to around three years old) from 20–45 m depth in an area between Farewell Spit and the south-eastern shore of Tasman Bay. The youngest age group first appeared in these samples between November and June, with highest catches recorded in June and July, suggesting seasonal movement away from shallow water in winter to warmer deeper water. Similar movements of 0+ tarakihi into deeper water in autumn have also been described in a nursery area in Tasmania (Jordan 2001). The juveniles in the Golden and Tasman Bays area were found to be closely associated with bryozoan beds for the first three years before moving into deeper waters and finally departing the nursery ground completely in their sixth year (Vooren 1975). This pattern is also apparent in recent west coast surveys where strong length modes for 0+ (10–14 cm) and 1+ fish (17–24 cm) were caught in Tasman and Golden Bays, but fewer 2+ fish (25–28 cm) (Stevenson & Hanchet 2010b). This area was known by local fishers as “*the coral*” and described by Vooren as containing “*an extremely rich benthic epifauna of sponges and small corals*”. This coral habitat consists of two species of bryozoans (*Celleporaria agglutinans*, and *Hippomenalla vellicata*) that historically occurred in three main areas; Separation Point, Torrent Bay, and west of D’Urville Island (Grange et al. 2003, Bradstock & Gordon 1983). Saxton (1980) described the history of commercial trawling in this area from the mid 1940s, which progressed from avoiding these foul areas to steadily “*breaking in*” the grounds as technology and new netting materials allowed. This was despite knowing that areas like Separation Point were “*home to big schools of small juvenile terakihi and snapper*” and noting that since fishing down the coral “*large bags of juvenile fish of the past are seldom taken these days*”. By 1980, the Torrent Bay bryozoan reef was virtually destroyed and an area around Separation Point was closed to power-fishing methods to protect the remaining bryozoan mounds in this area. This habitat was mapped and described by Grange et al. (2003) using ROV observations, and it was noted that the bryozoans were only growing from the distal tips and were covered by a film of silt, suggesting that the community may be stressed by sedimentation.

Vooren (1975) concluded that tarakihi nurseries were mostly some way offshore (10–30 km) in depths of 20–100 m and in a number of areas, also noted the presence of biogenic habitat in a number of these areas. Australian studies of this species note that nursery areas occur in inner and mid-shelf areas, often on unvegetated habitats (Jordan 2001). However, a number of anecdotal observations suggest that tarakihi nurseries also exist in rocky inshore areas unsampled by either commercial or research trawl surveys (Annala 1987). Small tarakihi less than 10 cm have been caught or observed by divers in a number of shallow harbours, estuaries and around rocky reefs; Graham (1956) described small fish (around 5–8 cm) as very common in Otago harbour between January and March, while Vooren (1972) reported similar small sized fish from inside Wellington Harbour between November and June. In more recent sampling, a national scale estuarine fish survey found two small juveniles in association with dead tree branches in Port Adventure (eastern Stewart Island) and another in association with green algae mats (*Enteromorpha* spp.) in Port Rose Estuary (north of Dunedin), in both cases in less than 1 metre water depth (low tide) (M. Morrison, unpubl. data). Diver observations of small fish, often in schools, in shallow reefs in the Napier region (Clinton Duffy, DOC pers. observ.), north-east of Nelson (Cole 2001), Hobo Bay at the Snares Islands (Debbie Freeman, DOC pers. comm., video footage) and in Tasmania over subtidal reefs adjacent to unvegetated habitats (Last et al. 1983).

Adult habitats

Around the North Island, Langley (1994) reported large catches on the west coast in the vicinity of Kaipara Harbour and along Ninety Mile Beach as well as off the North Cape and Great Exhibition Bay during the east Northland surveys, with lower catch rates throughout the rest of the survey area. A more recent trawl survey in east Northland caught modest amounts of tarakihi, mainly between 50 and 100 m, as well as tarakihi being the second most common species observed at baited camera stations down to 150 m (Jones et al. 2010). Low catch rates in previous Hauraki Gulf and Bay of Plenty trawl surveys are likely to be a result of insufficient depth range and/or timing respectively (Morrison et al. 2001b). Tong & Elder (1968) carried out a series of trawl surveys in the Bay of Plenty and found the largest catch rates between 100 and 200 m during autumn in the middle and eastern parts of the bay, which were slightly shallower in winter and summer. Highest catches on the lower east coast were generally between Tolaga Bay and Cape Runaway, mainly consisting of fish over 25 cm (Stevenson & Hanchet 2000a). With a broad pattern of being found in shallower depths in more southern (and colder) waters, tarakihi occur throughout the South Island, with highest catches in the west coast South Island trawl survey south from Greymouth at depths over 100 m and in Tasman Bay. Targeted surveys have been carried out on the east coast of the South Island; the most consistent trawl grounds were northern Pegasus Bay and Conway Ridge.

Tarakihi are abundant over soft muddy seabed in the East Cape region (Ayling & Cox 1987) and in Pegasus Bay they were historically associated with “*huge tracts of polychaetes referred to by some fishermen as ‘tarakihi weed’ which occur in the muddy sediment areas*” (Fenaughty & Bagley 1981). Further south off Otago, Graham (1956) found this species associated with all habitat types but noted that they preferred gravel habitats. They are commonly targeted by recreational anglers and spear fishers over foul ground, particularly along the edge of reefs and patches of algae, and occur (in low numbers) in fiords on the west coast (Francis & Ling 1985).

Adult migrations and movements

Movement in adult populations has received limited attention. Annala (1987) reported tagging studies carried out in various locations; while first year returns showed limited movement, fish at liberty for longer indicated more extensive migrations of over 300 km. Most recoveries were made north of the release site, many having travelled to the East Cape spawning grounds. Spawning migrations are well

known to fishers who described how, in the past, vessels in areas such as the East Cape region would be “*queuing up*” to fish during the day when the fish were close to the bottom (Jones & Morrison, unpubl. data). Similar targeted fisheries still continue in areas such as Cook Strait (Manning et al. 2008) and Kaikoura, where the target set net fishery takes place over two six week periods around January and May, most likely based on adult fish migrating to spawn (Field & Hanchet 2001). Beentjes (2011) found that most fish caught in this fishery were 30–40 cm, 4–7 years old and larger than tarakihi caught in trawl fisheries on the east coast of the South Island, which are generally smaller and younger than those from the WCSI, with few fish over 6 years old (Stevenson & Hanchet 2000b, Manning et al. 2008, Beentjes 2011). Comparing these recent survey and commercial data to that from the 1970s and 1980s, when both commercial catches and research vessel surveys showed a good representation (over 20%) of older fish (more than 10 years old and up to 30 years or more), Beentjes (2011) suggested that there has been a marked change in the size structure / age composition with the loss of virtually all fish above 10 years of age. He also noted the small proportion of spawning fish observed in both the set net and trawl fishery.

Population connectivity

Large-scale movements during both larval and adult phases and lack of genetic isolation suggest that tarakihi around New Zealand are a single stock, with the Australian and Chatham Islands populations being separate. However, within this single stock, size-structuring with depth, and regional differences in populations abundances are apparent in both New Zealand and Australian populations, and otolith microchemistry studies of Australian populations show some differences between areas indicating some level of subpopulation structuring (Thresher et al. 1994). A recent analysis of multiple lines of evidence for stock relationships in east coast tarakihi (both islands) suggested “*the amalgamation of the Bay of Plenty and East Cape–Mahia fishery areas (Statistical Areas 008–013) into a single stock unit. The spatial domain of this stock unit may also extend further south to include the Wairarapa coast, although there is also some suggestion (from catch and CPUE data only) that fish in this area may migrate to spawn in the southern area of TAR 2. The limited data from the East Northland fishery indicate that tarakihi in this area (Statistical Areas 002–004) are relatively distinct from the other fishery areas along the east coast of mainland New Zealand*” (Langley & Starr 2012). Research recommendations to improve our understanding of stock boundaries included: CPUE analysis of the key tarakihi fisheries within TAR 1, 2, 3, and 7; age frequency sampling of the commercial catch from key tarakihi fisheries; ageing of some existing otolith collections (east coast South Island and east coast North Island) and the reestablishment of the latter’s trawl survey series; directed sampling of the age composition of the spawning, adult component of TAR 2 and TAR 3 populations; tagging of the spawning population of tarakihi off East Cape; and re-instating the east coast North Island trawl survey (Langley & Starr 2012).

3.36 Trevally (*Pseudocaranx dentex*)

Fisheries catch

Commercial 3575 t¹

Recreational 300–900 t^{1*}

Sexual maturity: 25–35 cm / 3–4 years²

Maximum age: 40–45 years (c 50 cm)²

Pelagic phase duration

Eggs: 28 hours³

Larvae: 3–4 months



Photo credit: M. Francis, NIWA

¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; *Estimates of total recreational take were compiled across management areas for different years and using different survey methods. See Plenary document for caveats around use of these data; ²James (1984); ³James (1976); ⁴Masuda & Tsukamoto (1999).

Trevally (*P. dentex*) have a wide sub-tropical and temperate geographic distribution, encompassing New Zealand, Australia, Japan, the United States, the Mediterranean, Brazil and South Africa. They are a common coastal species around the North Island and the north-west of the South Island, mainly in less than 100 m depth (Anderson et al. 1998). Small juveniles are largely plankton feeders (Lowe 2013), while adult trevally feed on small free swimming prey, primarily using a behaviour known as ram-filtering or suspension feeding (Sazima 1998). Trevally appear to have a broad dietary preference, common prey including pelagic crustaceans, small squid, juvenile and larval fish (Sazima 1998).

Spawning

New Zealand and Australian trevally in spawning condition are observed predominately in spring and early summer (James 1984, Rowling & Raines 2000). Trevally are summer serial spawners meaning that they are likely to spawn several times in one season (Annala et al. 1999, Rowling & Raines 2000). Clearly defined spawning grounds have not been identified in New Zealand (James 1984). Gonad states have been recorded from trawl surveys in the south-east North Island (FMA 2), with ripe, running ripe and spent fish being found throughout the area, mainly in February (40%), but also in March and April. There are no records for other months.

Egg and larval transport

Trevally eggs are pelagic, and hatch about 28 hours after fertilisation (James 1976, Masuda & Tsukamoto 1999). In both New Zealand and Australia, trevally larvae are common in near shore coastal waters during late summer (Robertson 1975, James 1976, Smith 2003). Little is known about the distribution of trevally eggs and larvae in New Zealand, but they are thought to be widely distributed seasonally around the North Island's near-shore coastal waters (Robertson 1975). Eggs and larvae have been recorded north of 38° S (James 1976), although sampling of the neuston (near-surface) of the northern Hauraki Gulf over a year recorded only one larva (Tricklebank et al. 1992). Eastern Australia ichthyoplankton surveys have shown that larval trevally abundance is highest over the coastal shelf in less than 50 m water depth, and within 10 km of the shore (Smith 2003, Syahailatua et al. 2011a, b). Tank rearing studies show that the transition from larval to juvenile phases occurs over the first 50 days after hatching. At 50 days old, juvenile trevally average 30 mm long, with their eyes, lateral line, swimming musculature and fin rays being fully developed; and they display schooling and cruise swimming behaviours (Masuda & Tsukamoto 1999). Post-larval pelagic juveniles are attracted to objects such as detached seaweeds floating on the ocean surface.

Juvenile habitats

From about 40 mm in length, juvenile trevally start to become common in inshore areas, including estuaries and harbours. Sampling in estuaries has found them to be particularly associated with sub-tidal seagrass meadows, in particular in the Kaipara Harbour, and experimental work with artificial seagrass units has shown them to be preferentially attracted to higher blade densities (Morrison et al. unpubl. data). They are also found in association with other seafloor structure such as horse mussels, displaying a similar response as juvenile 0+ snapper. However, juveniles are also found in coastal habitats, including in association with some kelp forests, and it is unclear how differentially abundant they are across estuarine and coastal habitats. Current data suggests that they are probably reliant on estuaries on the west coast Northland, displaying very similar distributional patterns to juvenile snapper; being abundant in estuaries (albeit much more patchily); rare as small juveniles on the open coast; and with larger sized juveniles appearing first around coastal areas adjacent to harbour mouths, followed by a distributional expansion more broadly along the coast. On the east coast the situation is more complicated with 0+ juveniles being found not just in estuaries, but also in association with kelp forests in some areas, and even as communal cleaners in association with large old snapper (Leigh Marine Reserve, M. Morrison, pers. obs.). Large schools of 1+ fish can also be seen in semi-pelagic association with reef systems associated with high current flows (e.g. Horseshoe Reef, Whangateau Harbour, Auckland, and south-west of Aigulles Island, Great Barrier Island, M. Morrison, pers. obs.). Seasonal fine mesh set-net sampling in the Whangateau Harbour found 1+ trevally to be present in the harbour only over the summer period, suggesting ontogenic and/or seasonal migrations into and out of the harbour (Morrison 1997). Juveniles have also been caught in most parts of Pauatahanui Inlet, with a suggestion that shallow sandy areas were especially favoured (Healy 1980).

A trevally nursery ground in shallow waters of the North Taranaki Bight was suggested by Horn (1986), although catch rates were relatively modest in this area compared to later trawl surveys carried out further north on the same coast. Trawl surveys show that juveniles (0+ and 1+) occur mainly in less than 50 m depth around the northern North Island and occasionally off East Cape, in South Taranaki Bight and in Tasman Bay. The distribution of immature fish combined is similar. Around the northern North Island, catch rates were largest on the northwest coast (up to 2.4 t.km⁻²), while on the northeast coast, catches were highest in the Bay of Plenty, ranging up to 0.2 t.km⁻².

Adult habitats

In New Zealand adult trevally (over 25 cm) show both pelagic and demersal distribution patterns, and can form large schools in the water column and on the surface. Tagging suggests that these patterns reflect different seasonal behaviours of the same stock, and that fish are not from separate populations. (James 1984). Pelagic schooling is more common during the winter months, and is related to feeding. The large surface schools of trevally prevalent in the Bay of Plenty during winter feed primarily on krill (*Nyctiphanes australis*) (James 1984). Adults are also caught in southern North Island areas and occasionally on the west coast of the South Island, extending out to about 100 m depth.

Adult migrations and movements

James (1980) tagged 2676 trevally in the Hauraki Gulf, and western Bay of Plenty, in 1973 and 1974, with 130 returns (4.9%) over the subsequent five years (Figure 22). Movements of trevally were limited; 88% moved less than 30 nautical miles (55 km) from the release site. Fifty-seven percent moved less than 10 nautical miles (n.m.) (18.5 km), 31% between 11 and 30 n.m., 10% between 31 and 60 n.m., and 2% more than 60 n.m. The greatest movement was 133 n.m. (246 km) from Great Barrier Island to the area off Whakatane, with no correlation between distance moved and time at liberty. The data indicated some fish movement into shallow waters in spring, followed by a

movement back into deeper waters in summer, based on tag return rates from set nets (shallower) and trawls (deeper). This matched observations by set net fishers that trevally moved inshore at certain time of the year; however the effects of seasonal changes in fishing patterns as an alternative explanation could not be dismissed.

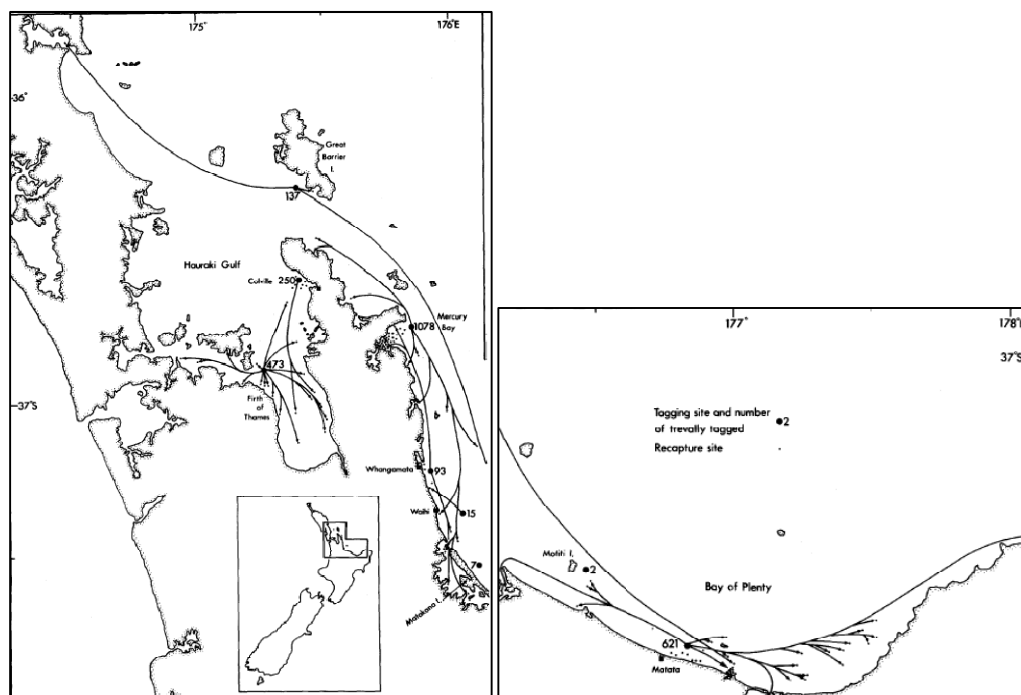


Figure 22: Tag and recapture sites and inferred movements of trevally (*Caranx georgianus*; now *Pseudocaranx dentex*) in the Hauraki Gulf and Bay of Plenty, 1973–1979. Black dots with associated numbers denote release locations and number of trevally tagged (Source: figure 1 of James 1984).

Population connectivity

Trevally fisheries are divided into three spatial areas: the west coast of the North Island (TRE 7); the northern east coast fishery including Hauraki Gulf and Bay of Plenty (TRE 1); and the east Wairarapa Coast (TRE 2). Trevally stock boundaries are poorly understood; there have been no published genetic studies looking at stock separation. The TRE 7 area population includes a reasonable proportion of fish greater than 20 years old, in contrast to the TRE 1 area which does not (Walsh et al. 2010), suggesting different stocks. Age structure information is available from the single trawl fishery on the west coast North Island (TRE 7). These data show different spatial patterns in age structure between Ninety Mile Beach, the main Kaipara-Manukau fishing grounds, and the southern Taranaki Bight (Walsh et al. 2012 press). Kendrick & Bentley (2010) also found different trends in commercial catch and effort for these TRE 7 sub-areas. Within TRE 1, differences are seen in the age composition of trawl catches between East Northland and the Bay of Plenty, suggesting that TRE 1 is made up of at least two sub-stocks; however the degree of spatial contrast in the age data is not as strong as seen in TRE 7 (Walsh et al. 2010). Age data is not available for TRE 2. However based on very high variation in CPUE the NINSWG concluded that TRE 2 is unlikely to comprise a separate stock and that it was probably linked to the stock in the BoP (M. Griffiths MPI, pers. comm.).

3.37 Trumpeter (*Latris lineata*)

Fisheries catch:

Commercial: 110 t¹

Recreational: 20–300 t^{1*}

Sexual maturity: 6–8 years / 45–50 cm²

Maximum age: 45 years / 120 cm³

Pelagic phase duration:

Eggs: Unknown

Larvae: 9–12 months⁴ (paper-fish phase)



Photo credit: M. Francis, NIWA

¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; *Estimates of total recreational take were compiled across management areas for different years and using different survey methods. See Plenary document for caveats around use of these data; ²Tracey et al. (2007) – for populations in Australia; ³Gomon et al. (1994), Paul (1999); ⁴Tracey & Lyle (2005).

The trumpeter is a latrid fish with a southern hemisphere distribution being found in cool temperate waters in depths between 50 and 400 m (Roberts 2003, Beentjes et al. 2010b). This distribution encompasses Australia, New Zealand, the Sub-Antarctic Islands of the southern Indian and Atlantic oceans, the Foundation Seamount in the central South Pacific, and possibly off Chile (Roberts 2003, Tracey & Lyle 2005). In New Zealand, trumpeter are more commonly found in waters between 50 and 200 m deep (Paul 1999). Trumpeter have been known to feed on euphausiids and amphipods (Fenwick 1978, Paulin et al. 1989), while research from Australia suggests that they are opportunistic carnivores with fish and cephalopods as part of their diet (Morton et al. 2005). Trumpeter may gather in loose schools in association with blue and copper moki (Ayling & Cox 1987).

Spawning

In Australian populations, females reach maturity at 44 cm and 5 years of age, compared with males at about 53 cm or 8 years of age (Morehead et al. 2005). In New Zealand, trumpeter are believed to spawn in winter (July) (Graham 1939b), compared to late winter to spring in Australia (peaking around September in Tasmania) (Ruwald et al. 1991, Furlani & Last 1993, Morehead 1998, Morehead et al. 1998, Furlani & Ruwald 1999). However, the New Zealand information is based on very limited sampling and it is uncertain whether this apparent difference between regions is real. Trumpeter may spawn close to shore (May & Maxwell 1986) but most likely in areas of deeper water, as they seem to migrate offshore to spawn (Beentjes et al. 2010b). This species releases its buoyant eggs into pelagic waters. Australian trumpeter are multiple spawners with batch fecundity estimates ranging from 205 054 for a 2 kg fish (540 mm FL) to 2 351 029 for a 9.5 kg fish (800 mm FL) (Tracey 2007). Australian researchers have found evidence of marked recruitment variability in trumpeter with particularly strong cohorts in some years and not in others (Morton et al. 2005).

Egg and larval transport

Trumpeter have an extended larval and postlarval stage, including a paper-fish phase, lasting up to 9 months in surface waters (Morehead, D. pers. comm., Tracey & Lyle 2005), resulting in extensive drift of young fish among different geographic regions. Although little is known about the transport of New Zealand trumpeter larvae, transport is likely to be similar to those of their Australian counterparts. Studies of Tasmanian trumpeter larvae have identified larvae in coastal waters off western Tasmania from September to October (Neira et al. 1998).

Nursery habitats

Australian trumpeter initially settle on inshore reefs (at depths of about 5 m) at the end of their long postlarval period, where they remain for several years, until they reach maturity and migrate into deeper areas (Murphy & Lyle 1999, Tracey & Lyle 2005). Small juvenile trumpeter (around 18 cm FL) are found on shallow reefs off south-eastern Tasmania in January (Murphy & Lyle 1999). Beentjes et al. (2010b) suggest that New Zealand trumpeter behave in a similar fashion to their conspecifics in Australia, with evidence indicating that migration offshore and maturation are closely linked. They estimate that 50% maturity occurs between 45 and 50 cm, while fish between 35 and 45 cm are probably immature and have not spawned. The New Zealand recreational fishery is therefore largely based on immature fish.

Adult habitats

Trumpeter occur from the Three Kings Islands down to the Auckland Islands, but are rare north of East Cape and Cape Egmont (Kingsford et al. 1988, Francis 1996, 2001). Trumpeter have also been sighted at the Bounty Islands (Freeman et al. 2011). Trumpeter occur mainly over rocky reefs and broken rubble (Beentjes et al. 2010b, Cole et al. 2012), ranging from shallow inshore waters to deep reefs on the central continental shelf (Beentjes et al. 2010b). Australian trumpeter are known to grow quickly over the first five years (Tracey & Lyle 2005), with growth slowing when they move further offshore (Tracey et al. 2006).

Adult migrations and movements

Although little is known about the larger scale migratory patterns of New Zealand trumpeter, Australian research has identified that some adults are highly migratory, with tagged fish travelling up to 650 km from Tasmania to southern New South Wales, and one fish travelling 5800 km from Tasmania to St Paul Island in the southern Indian Ocean (Lyle & Murphy 2002).

Population connectivity

In New Zealand, the only population information available for trumpeter comes from a six year survey (1994–99) in Paterson Inlet, Stewart Island (Chadderton & Davidson 2003). This survey utilised underwater visual counts, and comprehensive length-frequency distributions derived from just over 1000 fish caught by rod at 12–15 sites. The subsequent length-frequency data shows two or three clear juvenile cohorts which progress through time. Chadderton & Davidson (2003) interpreted this as evidence of variable annual recruitment pulses. The largest fish was 46.9 cm FL, with only a few fish over 40 cm in most years of sampling. This was consistent with evidence from Australia of an ontogenetic offshore migration at about 45 cm, though the migration is thought to occur at a slightly smaller size in the New Zealand population.

Australian trumpeter stock structure has been investigated. The recapture of a Tasmanian tagged fish from oceanic islands in the South Atlantic indicates that movements of adults of this species can be extensive, and therefore stock structures may be complex (Bruce et al. 2002). These large scale movements are consistent with a single circum-global genetic stock in the southern hemisphere, however, regional differences in otolith shape among populations from Tasmania, St Paul and Amsterdam Islands (Tracey et al. 2006) suggest that migration and interbreeding may be limited. In Australian waters a common trumpeter stock throughout its range is assumed for management purposes (Lyle & Hodgson, 2001). However, a molecular assessment of mtDNA and subsequent sequence analysis indicated that New Zealand striped trumpeter were genetically distinct from the Tasmanian and St. Paul/Amsterdam Island populations (Tracey 2007).

3.38 Yellowbelly flounder (*Rhombosolea leporina*)

Fisheries catch:

Commercial: 2467 t¹*

Recreational: 148–899 t¹*

Sexual maturity: 2+ years / 22–25 cm^{2,3}

Maximum age: 5 years / 45 cm^{2,3}

Pelagic phase duration:

Eggs: Unknown

Larvae: Unknown



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¹ For year ending 30/09/2011, MPI Assessment Plenary Document, Part 1, 2012; *Landings for eight combined species of flat fish. Estimates of total recreational take were compiled across management areas for different years and using different survey methods. See Plenary document for caveats around use of these data; ²Colman (1973); ³Muturo (2001).

The yellowbelly flounder is found in estuaries, embayments and shallow coastal regions (to a depth of 50 m) around the coast of New Zealand (Paulin et al. 1989, Anderson et al. 1998). It is abundant around the North Island but less so around the South Island (Muturo 2001), although trawl surveys have captured yellowbelly flounder in Tasman and Pegasus Bays (Hurst et al. 2000a). Juveniles feed largely on detritus and invertebrates (especially mysids), while crustaceans (crabs) and molluscs form the bulk of the adult diet (Livingston 1981, Park 1984, Pearks 1985, Muturo 2001, Lowe 2013). Livingston (1981) considered adult yellowbelly flounder to be predominantly nocturnal nonvisual feeders. There are significant yellowbelly flounder fisheries in the Hauraki Gulf, Kaipara and Manukau harbours (MPI 2012).

Spawning

Yellowbelly flounder adults move offshore to spawn between winter and spring (Tunbridge 1966a, Colman 1973). In the Hauraki Gulf, spawning occurs during September–October in a belt extending from Tapu on the eastern side of the Firth of Thames, north-westwards towards Ponui Island (Colman 1973). Larger juveniles disperse onto the spawning grounds from shallower waters during winter, and spawn for the first time as two-year-olds. Spawning takes place in water depths of 18–27 m (Colman 1973). Ripe and spent fish have been recorded also from Pauatahanui Inlet (Healy 1980), and from the Avon Heathcote Estuary (Webb 1972a), where they have a short breeding season in winter and spring (Webb 1972b).

Egg and larval transport

Rhombosolea spp. larvae have been sampled in the northern Hauraki Gulf from August to November (Tricklebank et al. 1992), probably consisting of sand and yellow-belly flounder individuals. Eggs of this species have been recorded from the Manukau Harbour from September through to December, with a peak in October (Pearks 1985). Eggs and larvae have been recorded from Pauatahanui Inlet (Healy 1980). Larvae were recorded off Otago from autumn to spring (Parsons 1999).

Nursery habitats

Juveniles appear to be exclusively limited to sheltered harbours and estuaries and have been found in many estuaries around New Zealand (e.g. Eldon & Kelly 1985, Healy 1980, Kilner & Ackroyd 1978, Colman 1973, Saunders 1999, Pearks 1985, Morrison 1998). Abundance is highest over the summer months (Healy 1980, Pearks 1985, Morrison 1998). National scale sampling of estuarine fish found them to be present in over three quarters (over 75 %) of the estuaries sampled (juveniles and adults

combined), although they were overall more abundant in northern New Zealand (Morrison et al. 2002, Francis et al. 2005, 2011).

Seasonal sampling in the Pahurehure Inlet, Manukau Harbour found high densities of small juveniles (25–100 mm) in summer along low-tide channel bank edges (Morrison 1998). Much lower densities of larger animals (75–150 mm) were present in the adjacent low-tide channels. Through autumn and winter the density of juveniles on the edge of the banks dropped substantially, while densities out in the channels proper increased. The average size of fish on the bank edges showed no change over a six month period, suggesting a combination of continued recruitment of smaller fish and emigration of larger fish. By winter, the highest densities of animals were located in 5–10 m water depth. This was taken to be evidence of an ontogenetic shift with age/size between estuarine habitats from shallow to deeper waters (Morrison 1998).

Adult habitats

Adults are most strongly associated with estuarine environments, but are also found in shallow coastal waters, especially in places that are ‘muddy’, such as the Firth of Thames. They have also been reported in the surf zone along some upper west coast North Island beaches, where they were historically targeted by some fishers (Anon. fisher, pers. comm. to M. Morrison). There are no empirical studies that link adult fish to specific habitat types or features.

Adult migrations and movements

Tunbridge (1966a) tagged 339 yellow-belly flounder across two sites in Tasman Bay, with 26 fish being returned (7.6%) (Figure 23). He reported that fish either moved from the deeper-offshore water (18–30 m) “*on to the shallow water mudflats and beaches*” from November to February; with local knowledge stating that fish move out into deeper water to spawn from July to September. Most fish moved less than 7 n.m. (13 km), but four fish moved between 10 to 15 miles; with one of those fish moving 15 miles over a 20 day period. Tunbridge concluded that fish spawned in the winter months, usually in deeper water, and this was the reason for their movements – although he also invoked flooding from rivers as having pushed fish out into deeper waters in December, resulting in two separate periods of inshore movement (this was speculation only). He argued that overall there was no evidence for any directional movement, and that “*the very shape of Tasman Bay and the proximity of suitable inshore areas, seems to preclude the need for extensive migrations*”, but also noted that tag returns were only made over a 9 month period, from October 1961 to May 1962.

Tunbridge also mentioned an earlier study for which we were unable to source the original report. Gorman (1960) reported a movement of tagged flounder (presumably both yellow-belly and sand flounders) down the coast of Canterbury, in a southwesterly direction against the prevailing north-west current which runs at 10 n.m (17 km) a day. It was suggested that this current transported the larvae back up the coast to where the adults had migrated from. Flatfish tagged inside Lake Ellesmere (sand, yellow-belly and black flounder) showed a random dispersal pattern within the lake, as well as movement out of the lake in winter, assumed to be a migration out to sea to spawn.

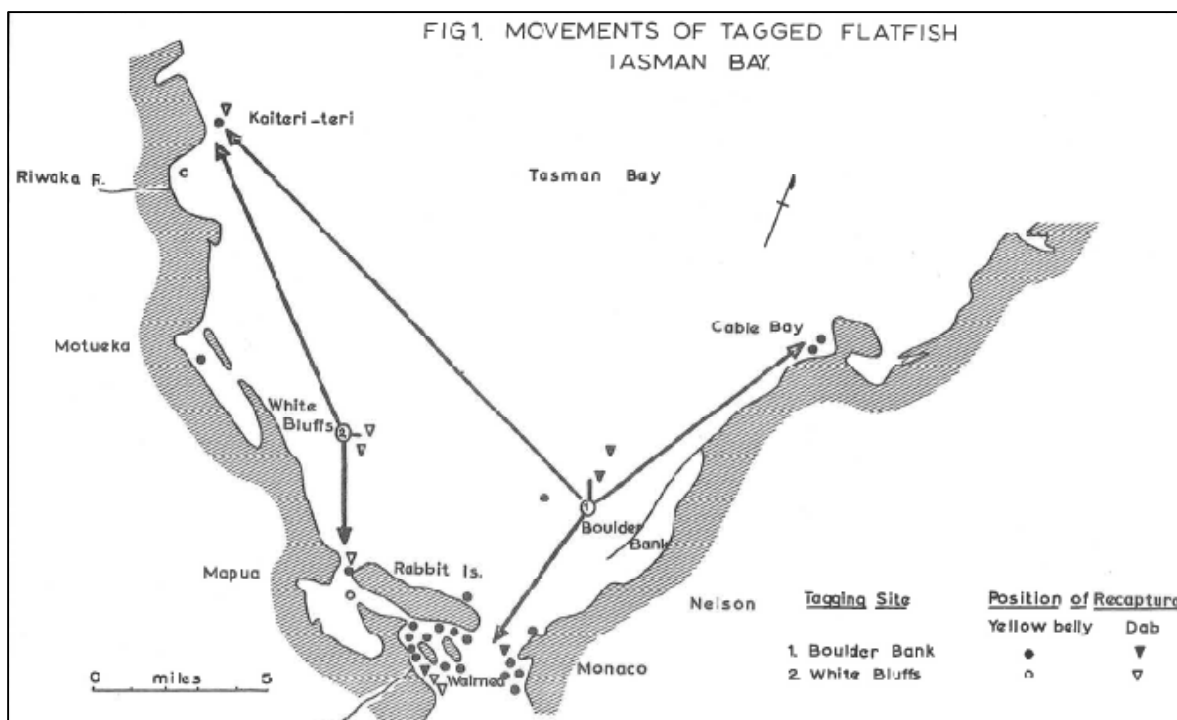


Figure 23: Movements of tagged yellow-belly and sand flounder in Tasman Bay. Source: figure 1 of Tunbridge 1966a.

Colman (1974) tagged 324 yellow-belly flounder in the Firth of Thames, with 80 returns (11%) (see Figure 16 in sand flounder section). All of the recaptures were considered to have come from the Firth of Thames (not all had detailed recapture site details), with no evidence of any movement outside the Firth of Thames. As with sand flounders tagged in the same project (see sand flounder section), returns in October and November were from the sea, while from December onwards most returns were from the Waihou River. Colman concluded that yellow-belly flounder migrated offshore to spawn in winter and spring, followed by an inshore movement after spawning into shallow water during the summer.

Morrison (1998) undertook a small scale juvenile and adult yellow-belly flounder (150–400 mm FL) tagging project in the Manukau Harbour to assess flounder residency in relation to exposure to sediment contaminants. Of 1170 fish tagged, 77 were recaptured over the first 1–6 months after release (multiple release events), with all but one being caught near their point of release (Figure 24), suggesting strong local site fidelity over the summer months (January–April) (average time at liberty 40 days, range 1–117 days). Only one fish moved a larger distance, with a 341 mm flounder being recaptured after 88 days at liberty to the north in the Kaipara Harbour (about 120 km away). Tag returns fell off sharply in winter, with only 5 returns in May, and 1 in June (after which tag monitoring ceased). It is not known whether tagged fish moved into deeper harbour waters where set-netters were not able to target them, or left the harbour. Concurrent CPUE estimates from research set-netting found a 50% decline in catch rates, which matches local fisher knowledge of poor flounder catches in the cold winter months. The disappearance of fish during the winter months from shallow water matches the data and conclusions of Colman (1974) and Tunbridge (1966a).

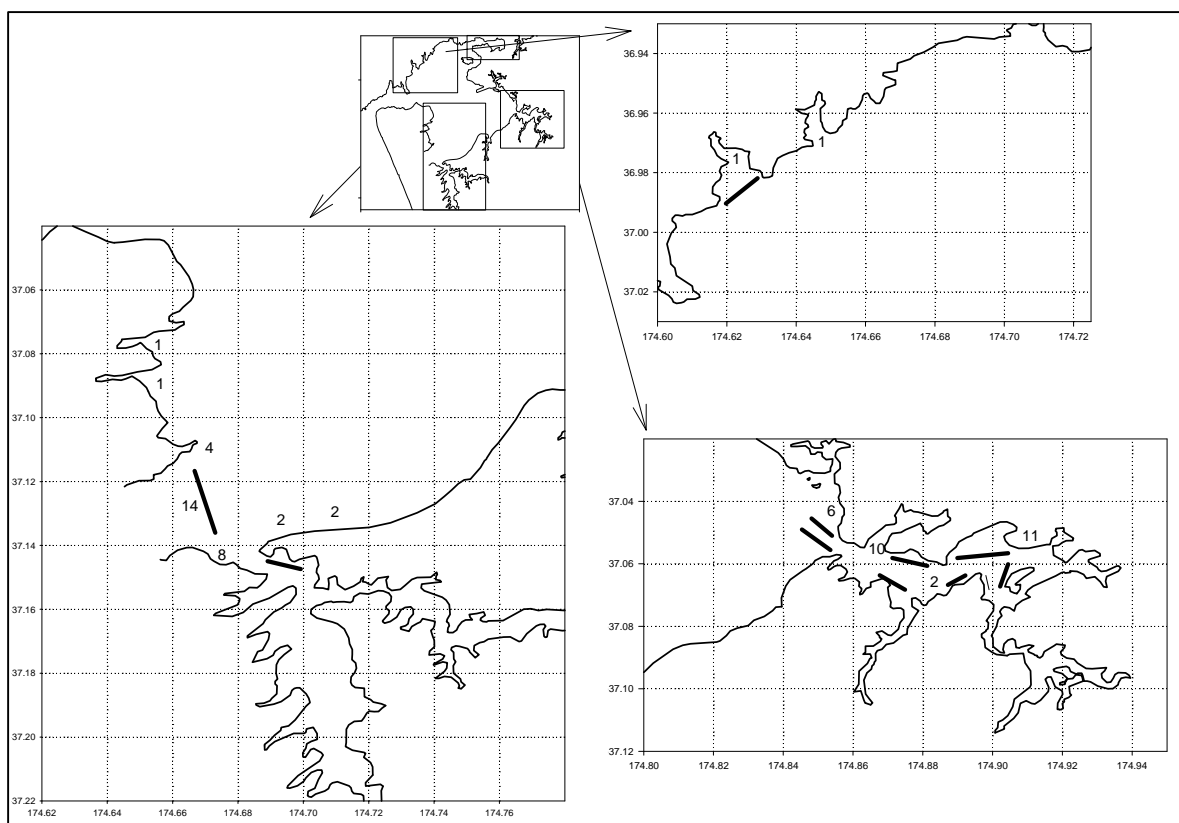


Figure 24: Yellow-belly flounder tag returns from fish released in the Manukau Harbour, for the first six months after release. Four locations were used for tagging – Mangere Inlet is not displayed as no fish were recaptured. Numbers in each 0.02 by 0.02 degree cell are the number of tagged individuals recovered, for the first 3–6 months after release. Only one fish moved outside its area of release, being recaptured in the Kaipara Harbour. The thick black lines denote where nets were set to capture fish for tagging. Source: Morrison 1998.

Population connectivity

No information is available.

3.39 Yellow-eyed mullet (*Aldrichetta forsteri*)

Fisheries catch:

Commercial: 38 t¹

Recreational: 30–100 t^{1*}

Sexual maturity: 22–24 cm / 3 years^{2,3}

Maximum age: 7 years⁴

Pelagic phase duration:

Eggs: Unknown

Larvae: 19 to 25 days²



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¹For year ending 30/09/2011, MPI Assessment Plenary Document, Part 3, 2012; ^{*}Estimates of total recreational take were compiled across management areas for different years and using different survey methods. Higher value includes “unassigned mullet”. See Plenary document for caveats around use of these data; ²Manikiam (1963); ³Webb (1973); ⁴Paulin & Roberts (1992); ⁵Pellizzari (2001) in Australia.

Yellow-eyed mullet occur around New Zealand, (including Stewart Island and the Chatham Islands), as well being found at Norfolk Island, and along the eastern, western and southern coasts of Australia, including Tasmania (FishBase 2012). Yellow-eyed mullet are widespread in shallow coastal waters from the surface to a depth of 50 m (more commonly down to a depth of 20 m). They are often found in schools in sandy or muddy bays, estuaries, and harbours around the coast as well as more coastal waters and reef areas (Taylor & Paul 1998, Curtis & Shima 2005, Francis et al. 2011). In general, yellow-eyed mullet are omnivores feeding on benthic detritus, small invertebrates, polychaete worms, fish and algae (Taylor & Paul 1998, Lowe 2013). Some fish may spend a significant amount of time in freshwater, and they have been recorded throughout the year in Lake Ellesmere, as well as in the Waikato River (Paulin & Paul 2006).

Spawning

Spawning occurs over summer from late December to mid March (Manikiam 1963) although in the Avon-Heathcote Estuary (east coast South Island) a biennial spawning with peaks in summer and winter is likely (Webb 1972b). No spent or post-spawned fish were found in Pauatahanui Inlet (southwest coast North Island) by Healy (1980), who suggested that adults went out to sea to spawn. Eggs are spawned close to shore (McDowall 1976).

Egg and larval transport

Larvae and juveniles are found in the neuston, up to at least 18 km from the shoreline (Kingsford 1985, Tricklebank 1988, Kingsford & Choat 1989), and are most abundant in open water and around drift algae from November to March (Tricklebank 1988). High densities have also been observed in the slicks of internal waves, which has been suggested as a mechanism promoting on-shore movements (Kingsford & Choat 1986). Neustonic juveniles have been observed being predated on by the white-fronted tern (*Sterna striata*) (Kingsford & Choat 1986). No larval fish were caught during fourteen months of sampling at a Whangateau Harbour estuary entrance (Roper 1986), suggesting that larvae develop away from shore, and return at a size where they are able to avoid sampling by plankton nets (Kingsford & Choat 1986, Kingsford & Tricklebank 1991).

Nursery habitats

Juveniles are a ubiquitous and cosmopolitan component of most estuarine fish assemblages, and are found universally across New Zealand estuaries, although they become less abundant going south, and are relatively uncommon at Stewart Island (Francis et al. 2005, 2011). While being found across most habitat types, they increase in abundance towards the upper areas of estuaries (Francis et al. 2011), and are absent from the lower open areas of large estuaries such as the Kaipara and Manukau harbours, thought to be in response to the larger number of predators (larger fish) in those areas.

Yellow-eyed mullet have been described by several researchers as ‘estuarine opportunists’ in that they regularly utilise estuaries but that they can also complete their lifecycle when they do not have access to this environment (Potter & Hyndes 1994). McDowall (1976) identified yellow-eyed mullet as one of several marine species that migrate in and out of river estuaries each day with changes of the tide.

Adult habitats

Researchers in Australia have identified that larger yellow-eyed mullet prefer deeper habitats such as channels and gutters on beaches while juveniles prefer the shallower bank sections of estuaries and beaches (Higham et al. 2005). In New Zealand, larger adult fish (30–50 cm) are only occasionally sampled in estuaries, and it is suspected that most juveniles display an ontogenetic migration into more coastal waters, and do not return. They are seldom caught in trawl surveys, probably as a combination of being most abundant in very shallow waters, and being found higher up in the water

column. Schools of adults have been observed over open coastal reefs (M. Morrison, pers. obs.), suggesting that fish may be wide-ranging from their original nursery grounds, and they are also eaten by a number of more open water predators including marine mammals such as dolphins and seals, as well as various coastal sea-birds.

Adult migrations and movements

No information is available.

Population connectivity

Curtis & Shima (2005) investigated growth rates of yellow-eyed mullet between different geographic regions around New Zealand using otoliths, and reported that populations had heterogeneous patterns of growth, both between sexes and across geographic locations, with no overall clear structuring.

4. CONCLUSIONS AND PRIORITIES FOR RESEARCH

Collectively, the coastal New Zealand finfish fisheries species examined in this review display a wide range of habitat affinities and geographical structuring, variation in age at maturity and longevity, and associated life histories (Tables 5, 6). Despite decades of fishing and associated research on fisheries stocks, our knowledge of most coastal fish species life histories, habitat usage and spatial structuring is arguably modest. Most work has been focussed on stock biomass, age and length population structures, and stock discrimination, at broad spatial scales. Collectively these work streams have addressed productivities at the scale of stocks, and the use of fishery dependent and independent (largely research trawl surveys, commercial catch-effort, and fisheries observers) data to monitor changes over time, to inform and direct fisheries management. Targeted research on the life history of species, including oceanography, habitat use, ontogenetic movements over time, and how populations / groups of populations (*sensu* 'stock(s)') are structured spatially, has been far less common.

Given the number of species involved, and stocks/populations within those species, it will not be practical to address all of the information gaps, nor to work on all species, in the short to medium term. The question then comes down to where and how best to invest relatively limited research resources for the best return, in terms of increased science understanding, and associated improved management, leading to improved medium to long term fisheries productivity for the species. This is only in part a science question: social and political pressures will also strongly drive such decisions.

From a fisheries research perspective (as opposed to a general ecosystem focus), selection of priority areas to invest research into will depend on a number of factors, including:

- The economic and social value of species: species of limited fisheries value (economically and/or socially) will be less likely to have significant research investments made in them. Where stocks are highly valued by 'society-at-large' either financially or socially/culturally, e.g. snapper in north-eastern New Zealand, and blue cod in the South Island, more effort is likely to be made to increase our understanding of their dynamics (e.g. blue cod in the Marlborough Sounds).
- The known or perceived threats to components of the life history – for instance some species (e.g., snapper, tarakihi, blue cod, leatherjackets) are linked in their juvenile phase to three-dimensional seafloor structures (e.g. biogenic habitat formers), which in turn are vulnerable to land-based threats such as sedimentation, and marine-based threats such as trawling and dredging over vulnerable seafloor habitats (e.g. bryozoan fields).
- Research 'tractability' in terms of the current availability of science tools and techniques to address the science questions asked. New powerful tools are continually appearing and evolving,

such as otolith chemistry, stable isotopes, and genetic approaches. Some problems that have been very difficult to address in the past, e.g., stock boundaries, and finer scale movement dynamics of juveniles, are being addressed using these evolving tools. Examples include snapper nursery grounds on the west coast of the North Island (Morrison et al. 2009), and source–sink systems for blue cod in Fiordland (Wing et al. 2012). Research ‘tractability’ also includes factors such as physical access to populations, and the spatial scales involved; e.g., species found in areas readily accessible by small coastal research vessels will be cheaper to work on than those in areas requiring larger ocean-going vessels.

- The potential to research multiple fisheries species at once, where different species may share the same habitats during some phase/s of their life histories. For example, Separation Point bryozoans are thought to provide a nursery function for tarakihi, snapper, leatherjackets, blue cod, and red cod (Vooren 1975): while northern New Zealand estuarine seagrass meadows in notably the Kaipara, Parengarenga, Rangaunu, and Tauranga harbours, and perhaps also Whangarei Harbour as it recovers, collectively support high densities of juveniles of fisheries species such as snapper and trevally, as well as the juveniles of other species such as parore, piper, and spotties (Morrison et al. 2009). Such clear functions of relatively easy to map habitats also make them more amenable to spatial management approaches.
- The ability to ‘scale up’ research findings to other situations or regions, so that findings are applicable well beyond the spatial domain of where the research was conducted. For example, species which require structured seafloor habitats in their early life phase, in particular where ‘habitat bottlenecks’ may be occurring, may have the same issues across their wider range. If so, identification of specific bottlenecks in one place or region may allow for the same or generically similar bottlenecks to be identified in other regions.
- The relative state of knowledge for different species and areas; to successfully generate hypotheses and test them usually requires that a broader background base knowledge is already available. For example, experimental tests of the value and role of different habitats are difficult to undertake, if a basic understanding of fish-habitat associations is not already available.
- The fit into wider societal objectives for ecosystems: including the development of Ecosystem Based (Fisheries) Management (EB(F)M) and Marine Spatial Planning (MSP), two inter-related philosophies currently being grappled with across many different countries. As an example of MSP, a range of agencies are currently working on developing an MSP for the Greater Hauraki Gulf in the context of the Hauraki Gulf Marine Park Forum, which includes ‘the identification and mapping of important juvenile fish nurseries and spawning locations’; yet these are relatively poorly known at present.

In the following we suggest briefly some avenues of research that might be particularly useful to undertake. This discussion is not meant to be exhaustive given the 40 or so species involved, arranged in multiple stocks around the country. However, the overlying theme across all of these suggestions is the importance of understanding where processes occur, e.g., being spatially explicit and ‘place-based’ is fundamental.

4.1 Spawning dynamics and aggregations

Most of the species reviewed show indications of forming spawning aggregations, often in association with large scale migrations to and from the spawning areas. While the general spawning areas may be known in some regions, exactly where spawners are found and their dynamics are usually not. However, such knowledge may be found in part from the knowledge of local commercial and recreational fishers, known as ‘Local Ecological Knowledge (LEK)’ in the science literature. As an

example, detailed spatial reporting of commercial snapper catches on both the west and east coasts of the North Island has revealed ‘hot spots’, where high CPUE is experienced annually during the snapper spawning season. Presumably these are areas of spawning aggregations by snapper that have been located by fishers over time; preliminary field investigations at some of these hotspots have confirmed that snapper were schooling in high abundance in mid-water, and that many of these fish were running ripe/milting (D. Parsons pers. obs.). Disturbance of such spawning aggregations by fishing or other activities may reduce their egg and larval production, including changing the dynamics of the remaining fish that are not physically removed. Many of these (presumed) aggregations occur immediately offshore of harbours and estuaries known to be important (if not critical) snapper nurseries, such as Parengareanga and Rangaunu harbours, the Bay of Islands, the Firth of Thames and inner Hauraki Gulf, and Tauranga Harbour, as well as other suspected areas such as the south-western region off Great Barrier Island. It is presumed that the siting of spawning aggregations maximises the likelihood of larvae reaching good nursery habitats, which in turn suggests spatial structuring (links between specific spawning areas and nursery habitats) at much finer spatial scales than that of ‘stocks’. A better understanding of local larval transport mechanisms (oceanography and larval behaviour) will allow for much improved spatial management. This argument also extends over other species, with a general observation that fish species tend to migrate upstream into current regimes for spawning, suggesting that eggs and larvae are subsequently transported back down-current. With climate change effects likely to include both stormier conditions (in both intensity and frequency) and possible changes in oceanography including currents, understanding such dynamics is likely to become increasingly more important. Other dispersal mechanisms may also be affected; including the association of juvenile pelagic forms with floating debris such as algal rafts (e.g. juvenile leatherjackets, kingfish, bass, and hapuku). Macreadie et al. (2011) have postulated that *“facilitation of long-distance dispersal of coastal organisms by macrophytic rafts may be severely modified by climate impacts on raft supply, quality, and persistence, and on transport processes”*.

4.2 Identification of nursery habitats and areas

While research trawl surveys and other methods have identified where juveniles occur for many fisheries species, the actual quantitative description of what it is about these areas that is important for the species has seldom followed. Better integration with other work streams, e.g., with seafloor habitat mapping (benthic) and oceanographic regimes (pelagic), would advance our understanding and ability to create maps of important habitats and related dynamic processes. Standard fisheries trawl surveys are also limited in where and what they can sample; areas excluded include rougher seafloors such as reefs and sharp topographies, areas close in around features such as islands and submerged reefs, and water depths of 10 m or less. Trawl surveys also have issues around timing and gear selectivity, as they are usually designed for purposes such as monitoring of adult biomass of stocks, rather than new investigative and targeted research, meaning that juveniles occurring during particular seasons in particular habitats may be easily missed. Dedicated surveys to find and quantify juvenile nursery grounds would be ideal, and not necessarily using standard trawl surveys as the sampling approach. Generally, juvenile life history phases are the most likely to suffer habitat bottlenecks (*sensu* Werner & Gilliam 1984) or other recruitment limiting processes, which in turn constrain the potential productivity of adult populations and associated fisheries.

4.3 Connectivity of juvenile habitats with adult habitats

As well as oceanographic connectivity between spawning grounds and settlement habitats/juvenile nurseries, post-recruitment (in an ecological rather than fisheries sense) ontogenetic connectivity

between nursery grounds and adult populations is also critical. Virtually all of the species reviewed here were found to have evidence of juveniles moving over time out of nursery areas into the wider ecosystem. This form of connectivity links habitats and areas with each other, and is a fundamental part of spatial population dynamics, at scales below that of stocks. Quite limited areas may provide recruitment to most of the adult distributional range, making them vulnerable to ‘far field’ effects, or alternatively many small local nurseries may collectively contribute. The nursery definitions of Beck et al. (2001), Dahlgren et al. (2006), and variants thereof (e.g. for elasmobranchs) have not yet been applied for any New Zealand coastal fisheries species, with the exceptions of mangrove fish assemblages (Morrissey et al. 2007, 2010) and west coast North Island snapper (Morrison et al. 2009). The spatial scale of such connectivity is likely to vary widely across species – for instance, sand flounder nursery-adult grounds may be structured at the tens to hundreds of kilometres (Colman 1974, 1976), while tarakihi may be structured at the scale of hundreds to thousands of kilometres, with most of the nursery grounds being found around the South Island, yet most of the adult fisheries catch being taken off northern New Zealand (Vooren 1975). Other species may have even larger connectivities, with suggestions of possible links with Australian populations, such as for blue mackerel, or even South America, as shown by Murphy’s mackerel, *Trachurus murphyi*. Understanding the scales of connectivity involved, and more specifically the spatial dynamics between different nurseries and adult grounds, needs more attention. Source and sink dynamics may be especially important, with some nurseries (sources) effectively supporting other areas that are unable to be self-sustaining (sinks). Current work underway includes linking juvenile grey mullet nurseries (which is an estuarine dependent species) to adult populations around northern New Zealand, which occupy a diverse range of freshwater and coastal habitats; and juvenile snapper nurseries in East Northland to adult populations, including an attempt to quantify the relative contributions of estuarine versus coastal nursery habitats.

4.4 Adult movement dynamics

Migratory behaviour of adults, especially in relation to spawning, is a common behaviour of many (but not all) of the species examined in this review, along with evidence of several different behavioural morphs in some populations (e.g. both resident and migratory components) (see Table 1). We expect that such behavioural variation is actually widespread across many fisheries species, and it simply has not been fully appreciated and looked for to date (Kerr et al. 2007). Many fisheries also appear to be seasonal and either target migrating fish as they pass through a fisheries region, or when they aggregate to spawn, suggesting both impacts on the migratory process in general, and possible differential removal of behavioural morphs (see Parsons et al. 2011 for a New Zealand example involving snapper). The key work by Kerr, Secor and others on white perch (see concepts section) suggest that these different behaviours may have important consequences for fish populations, including stability, resilience and productivity. Such dynamics are not currently allowed for in fisheries management strategies. While a number of tagging programmes have been undertaken on coastal finfish fisheries species in New Zealand, they have tended to be *ad hoc* (e.g., tagging fish as practical, piggy-backed on other trips), and have not accounted for spatial and temporal variation in fishing patterns confounding movement patterns (note: most authors have explicitly noted the latter issue; but have not had the resources nor data to address it). While tagging programmes are intuitively very attractive, given that tag and recapture patterns can easily be mapped, in reality they are quite complicated when trying to estimate actual movement rates. As discussed by Dingle & Drake (2007), migration and movement can be characterised into a number of different categories, several of which may be operating at the same time within a population. Past tagging programmes in New Zealand have not distinguished between these categories, and it is likely that some of the unexplained ‘noise’ and

lack of clear pattern in some of these studies may actually be due to different behavioural distributions being viewed as one distribution only. It also appears that many analyses (or rather interpretations as formal analyses are often not possible given the data), do not account for the potentially ‘circular statistics’ involved, as fish migrate and return each year (assuming some form of annual homing is involved). In this scenario, distance moving with time will only increase up to a point, followed by a reduction as fish return to the general tagging areas. Where and when fish are tagged in this process will profoundly affect the data collected, in particular fish tagged across multiple places and times (often multiple years) will result in a high level of noise, unless some predefined hypothesis has been provided that explicitly allows for these effects in the data returns. Despite these issues, we believe that carefully targeted tagging programmes, with clear hypotheses around what movement mechanisms are being tested, offer powerful ways forward. The strength of such work will be much enhanced if bundled with other complimentary approaches such as natural markers (e.g. otolith chemistry, stable isotopes and genetics tools) and oceanographic monitoring and models. As an example, current work on snapper migration from the inner Hauraki Gulf to surrounding areas, including migratory and resident behaviour and potential sources and sinks; is using both conventional tagging (external dart tags) and otolith chemistry. This work also encompasses looking for markers for different movement morphs and an examination of growth rates of returned fish from different groups to see if movement behaviour can be related to fish productivity.

Table 5: Summary of aspects of species life histories. See individual species sections for data sources.

Species	Egg phase (days)	Larval phase	Sexual maturity (length in cm, M = male, F = female)	Sexual maturity (years)	Maximum age (years)	Commercial catch (t)#	Recreational catch (t)## (Time period for data presented given in brackets)
Banded giant stargazer	–	–	79	–	–	–	–
Barracouta	2.1	–	50–60	2–3	10	32 672	250–500 (1999–2000)
Blue cod	5	5 days	10–19 (Northland) 21–26 (Marlborough) 26–28 (Southland)	2 3–6 4–5	32	2 342	706–1681 (Estimate of all areas combined, from available data 1991– 2000).
Blue mackerel	–	35 days	23.6 (M), 28.7 (F)	2	24	8 638	35–90 (Estimate for EMA 1 based on several years data up to 2001).
Blue moki	–	8–12 months (paper-fish)	40	5–6	43	574	117–245 (Estimate for MOK 1, 3, 5. Data from 1996 & 1999–2000).
Blue warehou	4	–	37	4–5	23	2, 924	20–30 (Estimate based on limited info. for central and southern regions, 1991 & 1992)
Butterfish	5–7	–	22.9–29.7 (Hauraki Gulf) 25.2 (Stewart Is.)	1–2 4	10 (Northland) 19 (Stewart Is.)	116	67–180 (Estimate of all areas combined, from available data 1991– 2000).

Species	Egg phase (days)	Larval phase	Sexual maturity (length in cm, M = male, F = female)	Sexual maturity (years)	Maximum age (years)	Commercial catch (t)#	Recreational catch (t)## (Time period for data presented given in brackets)
Elephant fish	N/A	25–34 weeks (egg case)	50 (M), 70 (F)	3 (M), 4.5 (F)	>10	1 384	(3500 fish) (1999–2000)
Frostfish	–	–	97 (M)*, 111 (F)*	–	8*	1 106	Occasionally caught.
Gemfish	–	–	60–70	4–6	15	860	(5500 fish) (1996)
Giant stargazer	–	–	40–55	5–7	25	3 203	(1500 fish)
Grey mullet	–	–	33–35	3	14	826	100–150 (Estimate for GMU 1 based on several years data: 1993, 1996, 2000)
Hake	–	–	67–75 (M), 75–85 (F)	6–10	25	5 837	Negligible
Hapuku	–	–	80–85	10–13	60	1 543	100–700 (Estimate of all areas combined, from available data 1991–2000).
Jack mackerel (all species combined)	–	–	26–30	2–4	26–30	40 031	80–110 (Estimate for JMA 1 based on several years data: 1993/94, 1996, 2001)
John dory	12–14	–	23–29 (M), 29–35 (F)	2	9–12	637	75–303 (Estimate for JDO 1 & 2)

Species	Egg phase (days)	Larval phase	Sexual maturity (length in cm, M = male, F = female)	Sexual maturity (years)	Maximum age (years)	Commercial catch (t)#	Recreational catch (t)## (Time period for data presented given in brackets)
							based on several years data: 1992–94, 1996, 1999/2000)
Kahawai	–	–	40	3–4	26	2 221	1000–1500
Kingfish	–	–	83 (M), 97 (F)	8–10	20	171	500–700 (Estimate for KIN 1 based on several years data up to 2001. KIN 1 & 8 contain most of recreational catch)
Leatherjacket	–	22–66 days	19–22	2	7	573	Negligible
Lemon sole	4	–	–	2	6–7	2 467*	<30
Ling	–	–	65–100	6–11	30	12 337	15–40 (Estimate for LIN 1 based on 1993–1994 data)
New Zealand sole	–	–	–	–	–	2 467*	–
Red cod	–	–	45–55	2–3	6	6 691	205–388 (Estimate of all areas combined, from available data 1996, 1999–2000).

Species	Egg phase (days)	Larval phase	Sexual maturity (length in cm, M = male, F = female)	Sexual maturity (years)	Maximum age (years)	Commercial catch (t)#	Recreational catch (t)## (Time period for data presented given in brackets)
Red gurnard	–	8 days	23	2–3	16	3 289	300–500 (Estimate of all areas combined, from 1999–2000 data).
Rig	N/A	11 months (gestation)	85 (M), 100 (F)	4–6 (M), 5–8 (F)	20	1260	200–450
Rough skate	N/A	Possibly 4–5 months (egg case)	52 (M), 59 (F)	4 (M), 6 (F)	9	1882	Rarely caught
Smooth skate	N/A	Possibly 4–5 months (egg case)	93 (M), 112 (F)	8 (M), 13 (F)	28	609	Rarely caught
Sand flounder	4.75–5	>10 days	18–25 (M), 25–30 (F)	2	5	2 467*	148–899
School shark	N/A	12 months (gestation)	120–135 (M), 130–140 (F)	12–17 (M), 13–15 (F),	50+	3 469	75–302 (Estimate of all areas combined, from available data 1991–1994 & 1999–2000).
Sea perch	N/A	Up to 52 days	19–25 (M), 15–20 (F)	5–7 (M), 5 (F)	32–43	1 506	(750 000 fish)
Silver warehou	6	–	45	4–6	19 (M), 23 (F)	8 004	No recreational fishery
Snapper	1.5	18–32 days	20–28	3–4	60+	6 355	About 3 000 (Using most recent aerial overflight data, 2005–06 and 2007).
Spiny dogfish	N/A	24 months (gestation)	58 (M), 73 (F)	6 (M), 10 (F)	21 (M), 26 (F)	6026	234 (Estimate of all areas)

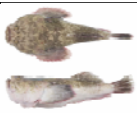
Species	Egg phase (days)	Larval phase	Sexual maturity (length in cm, M = male, F = female)	Sexual maturity (years)	Maximum age (years)	Commercial catch (t)#	Recreational catch (t)## (Time period for data presented given in brackets)
							combined, from 1999–2000 data).
Tarakihi	–	7–12 months (paper-fish)	25–35	4–6	30+	5708	300–800
Trevally	1.2	50 days larval, then pelagic phase	25–35	3–4	40–45	3575	300–900
Trumpeter	–	9–12 months (paper-fish)	45–50	6–8	45	110	20–300
Yellow-belly flounder	–	–	22–25	2+	5	2467*	148–899
Yellow-eyed mullet	–	19–25 days	22–24	3	7	38	30–100 (Estimate of all areas combined, from 1999–2000 data)

*Denotes values from the Mediterranean.







Denotes Commercial Catch data for the 12 month period prior to the 30/09/2011. * Denotes value is for eight flatfish species combined.






Denotes Recreational Catch data from MPI Assessment Plenary Document (2012); Estimates of total recreational take were compiled across management areas for the most current data year available (so this may vary between species). See Plenary document for caveats around these estimates.








Table 6: Summary of species distribution and movement dynamics.





Species	Area and habitats	Ontogenetic Shifts	Evidence of spawning migrations	Evidence of migration / partial migration / behavioural morphs?	Stocks/populations	Key references
Banded giant stargazer (<i>Kathetostoma binigrasella</i>) 	Southland, Snares, eastern Chatham Rise, west coast of North Island at a depth of 100–300 m.	No information available	No information available	No information available.	No information available.	Hurst et al. (2000a)

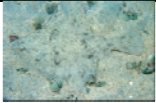




Barracouta (<i>Thyristes atun</i>)		Around New Zealand; nursery areas include Tasman and Golden Bays, Canterbury Bight and Pegasus Bay. Depth range 50–450 m.	Limited information, but adults have a wider distribution than juveniles.	Spawning aggregations occur around the country, which are targeted by fishers. Extensive movements between feeding and spawning grounds, tag returns up to 500 n.m.	No information available.	At least three separate barracouta spawning stocks: east coast North and South Islands; west coast South Island; and Chatham Islands.	Hurst & Bagley (1989), Langley & Bentley (2002)
Blue cod (<i>Parapercis colias</i>)		Nationwide but more common in South and the Chatham Islands. Found in depths of 50–150 m.	Some indications that small juveniles may move in from habitats outside of adult habitat in shallow areas – but unclear in general.	Unclear. Tagging returns show larger scale movements to occur for a small number of tagged fish; but most are recaptured close to release sites.	Unknown. A range of movement distances have been recorded across different tagging programmes in different areas, so mobile and resident morphs are possible.	Likely to be a number of discrete populations /stocks.	Rapson (1956), Mace & Johnston (1983), Mutch (1983), Carbines & McKenzie (2001), Carbines & McKenzie (2004), Carbines & Cole (2009)
Blue mackerel (<i>Scomber australasicus</i>)		Pelagic, predominantly occur around northern New Zealand.	Juveniles occur in less than 100 m water depth, larger fish extend into deeper water.	No information available	No information available.	At least three stocks in EMA 1, EMA 2, and EMA 7.	Hurst et al. (2000a), Smith et al. (2005)
Blue moki (<i>Latridopsis ciliaris</i>)		Predominantly found along the east coast of the lower North Island, South Island, and Stewart Island. Also common at the Three Kings Islands. Found down to 250 m.	Yes, juveniles associated with rocky reefs, adults more broadly found also over sand and mud. Long paper-fish phase, settle from plankton as juveniles 8–10 cm long.	Yes, seasonal moki ‘run’ up the east coast from at least Kaikoura north to Gisborne region – indicated by patterns of commercial catch, reproductive condition, and limited tagging. Bay of Plenty fish are thought to migrate past Cape Runaway to the same spawning ground	Tagging data shows a general spawning migration, but also individuals that do not fit this pattern, suggesting partial migration or other effects. Fishers also report two forms of fish: migratory (clean white flesh) and resident (streaky black lines through the flesh). Seasonal ‘runs’ targeted by fishers in depth bands.	Likely to be one highly connected stock along the east coast of New Zealand	Francis et al. (1981a), Langley & Walker (2004)
Blue (common) warehou (<i>Seriotele brama</i>)		Lower North Island and South Island, more common in the south. Found in depths of 5–400 m.	0+ fish are found in less than 75 m water depth, relatively high abundances of juveniles, known hotspots include Tasman and Golden Bays.	Blue warehou are thought to undertake substantial spawning migrations. The seasonal patterns of blue warehou landings suggest that there is an annual coastal migration for this species.	No information available.	Bagley et al. (1998a) suggested four stocks: a southern population; a central eastern population; a south western population and a north western population.	Bagley et al. (1998a), MPI (2012).
Butterfish (<i>Odax pullus</i>)		Across New Zealand, but more common in the south. Found in depths of 10–40 m.	Juvenile fish are found in the shallower parts of coastal rocky reef systems supporting brown kelp forests, and undergo an ontogenetic shift with age into the deeper parts of the adult range.	Knowledge of movement in this species is very limited. At fine scales, butterfish are active during the day, making regular migrations across reefs to different depths, depending on tidal state.	No information available.	Unknown.	Ritchie (1969), Paul et al. (2000), Pérez-Matus & Shima (2010), Cole et al. (2012)
Elephant fish (<i>Callorhynchus milii</i>)		Most common along the east and south coasts of the South Island down to	Eggs are laid in shallow areas such as Marlborough Sounds, Pegasus Bay and Canterbury Bight. Small juveniles are	Adults aggregate in shallow inshore waters (including harbours, bays and estuaries) during spring to mate and	No information available.	Likely that sub-populations exist in different areas with as yet unidentified nursery areas	Gorman (1963), McClatchie & Lester (1994), Francis (1997a),






	around 150–200 m depth.	found in shallow inshore areas.	females separating to lay their eggs. After spawning, adults move back offshore into deeper water during the summer months and remain deep during winter.		supporting them.	Braccini et al. (2008)
Frostfish (<i>Lepidopus caudatus</i>) 	Around the continental shelf. Found in depths of 50–600 m.	Juvenile frostfish (under 30 cm) have been sampled through research trawl surveys from off Northland, the Hauraki Gulf, the Bay of Plenty, and the west coast of both the North and South Islands.	Known spawning areas include the outer continental shelf, from the Bay of Islands to the south of East Cape in the North Island; and the west coast of the South Island.	No information available.	Proposed a) Bay of Islands to East Cape region, known spawning area; b) Fiordland, Puysegur Bank and Steward/ Snares shelf known spawning area, c) west coast South Island, where most of the commercial catch was taken, and a known spawning area occurs.	Robertson (1980a), Bagley et al. (1998b)
Gemfish (<i>Rexea solandri</i>) 	Around New Zealand. Found in depths of 200–600 m.	Young gemfish are most often recorded from the west coast of the South Island and the Bay of Plenty, consistent with the distribution of ripe females. Some suggestion of associations with foul ground.	Strong seasonal patterns of commercial fishing occur around the North and South Islands from which spawning migrations are strongly inferred.	No information available.	Thought to be two stocks; off the east and north of the North Island, and another off the west and south of the South Island.	Langley (1995), Renwick et al. (1998), Horn & Hurst (1999).
Giant stargazer (<i>Kathetostoma giganteum</i>) 	Around New Zealand in depths ranging from 10–900 m.	Areas of higher juvenile abundances occur off the east and west coasts of the South Island and in Tasman Bay.	There is no evidence for discrete spawning areas, with spawning thought to take place mainly in winter months on outer shelf to slope areas throughout New Zealand.	No information available.	Unknown.	Beentjes et al. (2010a), Stevenson and Hanchet (2010)
Grey mullet (<i>Mugil cephalus</i>) 	Generally restricted to more northern temperate waters, with the main fisheries being in the upper half of the North Island. Usually in depths of 1–10 m.	Juvenile grey mullet occur in almost all of northern New Zealand's estuaries, and the species is thought to be estuarine dependent in New Zealand.	Grey mullet movements are poorly understood in New Zealand, but tag returns show movements along surf beaches from one estuary to another.	It is suspected that there is considerable fine spatial structuring in New Zealand grey mullet populations and that migratory dynamics are diverse within populations, including resident and migratory morphs.	There are no studies from New Zealand of how grey mullet populations are structured, and currently the species is managed as one single stock (GMU 1).	Hutton (1872), Hore (1988), Chang et al. (2004a, b), Paulin & Paul (2006), Morrissey et al. (2007)
Hake (<i>Merluccius australis</i>) 	Hake are widely distributed south of 40°S, in water depths of 250–800 m.	Juveniles (0+) are often found in less than 250 m water depth.	In the New Zealand context, little information exists on movement. Globally, most hake species make seasonal migrations moving inshore and to lower latitudes to spawn in summer, and then back offshore and to higher	Different behavioural groups (resident versus migratory) are known from overseas hake species. The distinctiveness of inshore (resident) fish versus offshore (migratory) groups is consistent across hake (<i>Merluccius</i>) species, with	Three stocks are recognised in New Zealand waters: the Challenger Plateau and west coast of the South Island (HAK 7), the eastern Chatham Rise (HAK 4), and the rest of	Colman (1998), Arkhipkin et al. (2003), Ballara (2012).


			latitudes to their feeding grounds in winter.	associated clear population genetic structure along complex coastlines, but not along linear ones.	the EEZ (HAK 1).	
Hapuku (<i>Polyprion oxygeneios</i>) 	Around New Zealand and the Chatham Islands, mainly on foul ground in 100–400 m of water; but were historically abundant right into very shallow water.	Small pelagic juveniles spend about two years in the plankton, and associate with drifting debris. At 40–50 cm they become demersal and occupy water less than 200 m depth. Some evidence of large seasonal schools of juveniles.	Migrations/movements are substantial, and are thought to be related to spawning.	No information, but tagging data shows both resident and more mobile fish, with distances moved ranging up to 1389 km.	Paul (2002a) concluded that existing data was insufficient to quantify what stock structure might exist.	Graham (1939a), Beenjtes & Francis (1999), Paul (2000), Paul (2002a, b c), Paul (2005a, b), Wakefield et al. (2010)
Jack mackerel (<i>Trachurus declivis</i>) 	Around the country, more common in the north. Found between 30 and 300 m deep.	The distributions of 0+, 1+, and all juveniles combined are consistent with known spawning areas.	Spawning is suggested to occur throughout the species range.	No information available.	Not known.	Jones (1990), Kailola et al. (1993)
Jack mackerel (<i>Trachurus novaezelandiae</i>) 	Common around northern New Zealand. Found in waters shallower than 150 m.	The distributions of 0+, 1+, and all juveniles combined are consistent with known spawning areas and the distribution of the adults.	Multiple spawning areas are known.	No information available.	Unclear.	Horn (1991), Crossland (1981a, 1982)
Murphy's mackerel (<i>Trachurus symmetricus murphyi</i>) 	Mainly around the South Island, the Chatham Rise and southern North Island. An invasive species (by natural processes) from Chilean waters. Found in depths of 30–400 m.	Juveniles (under 30 cm) recorded in research trawls from the east coast of the North Island, South Taranaki Bight and a few from the west coast South Island. Some evidence that the east coast of the North Island is an important nursery area for early life history stages. Suggested offshore movement with increasing size.	New Zealand spawning is thought to occur.	No information available.	Data supports the hypothesis that <i>T. murphyi</i> in the New Zealand region are a small, and perhaps periodically separated, component of a larger South Pacific stock which undergoes periodic expansions or migrations.	Taylor (1999a, 2002, 2004), Ward et al. (2012).
John dory (<i>Zeus faber</i>) 	Three Kings to Foveaux Straight and around Chatham Islands out to 200 m; most common in less than 50 m.	Juveniles widespread and most abundant in 50–100 m water depth.	Danish seiners target small aggregations in the Hauraki Gulf seasonally, but it is not known if these are related to spawning. Very little is known about John dory movement. Adults move out into deeper water in the Hauraki Gulf in summer, with a shallower inshore distribution in winter.	No information available.	Not known. It seems likely that localized populations exist; maintained by feeding, spawning and juvenile nursery habitats on a relatively local scale, with some evidence that biogenic habitat areas may be important in the juvenile stage.	Hore (1982, 1985), Langley (1994), Hanchet et al. (2001), Morrison et al. (2001b)
Kahawai (<i>Arripis trutta</i>)	Around the country, but more common around the North Island and on the east	Juveniles are found in estuaries and along coastal beaches.	The spawning habitat of kahawai is unknown but is thought to be associated with the seabed in deeper offshore	No information, but tagging data shows both resident and more mobile fish, with distances moved ranging up to	Unknown.	Wood et al. (1990), Jones et al. (1992), Griggs et al. (1998),

		coast of the South Island. Found in waters up to 200 m.		waters (i.e. 60–100 m).	743 n.m.		Hartill & Walsh (2005)
Kingfish (<i>Seriola lalandii</i>)		Widely distributed around the North Island and the northern half of the South Island, generally in depths of less than 150 m.	Juvenile kingfish and their habitats are very poorly known in New Zealand. Small fish of less than 300 mm in length are thought to associate and drift with flotsam and drift seaweed far offshore, for around one year.	Anecdotal evidence suggests that kingfish spawn across a range of settings, from estuaries out to deep water.	No information available. Tagging work shows most fish to be resident at the scale of tens of kilometres; large movements are also reported of up to 410 n.m around New Zealand, as well as large movements to Australia, along with recaptures from Lord Howe Island and Wanganella Banks.	Although kingfish are capable of moving very large distances, indications from tagging are that most adult kingfish stay within localised areas in New Zealand.	Walsh et al. (2003), Holdsworth & Saul (2011)
Leatherjacket (<i>Parika scaber</i>)		Found around most of the country, especially in association with rocky reef habitats, more common in the north. Found in depths of 40–60 m.	Juvenile leatherjackets recruit into the heads of <i>Ecklonia radiata</i> kelp plants on rocky reef habitats. It appears that the kelp heads are the principal settlement and initial growth habitats for this species.	Leatherjackets spawn around nest sites prepared and guarded by the male of the species in spring and summer.	No information available.	Unknown.	Poynter (1980)
Lemon sole (<i>Pelotretis flavilatus</i>)		Around the country, but more common in the South. Found in waters more than 50 m deep.	Strong depth versus size relationship, with smaller lemon sole occurring in shallower inshore areas (15 m water depth) and larger individuals occurring in deeper waters (30 m water depth).	Rapson (1946) considered that schools of spawning fish moved about over large spatial scales, with males tending to congregate on the spawning grounds before females, and remain there longer after spawning had occurred.	No information available.	Unknown.	Rapson (1946), Roper & Jillett (1981)
Ling (<i>Genypterus blacodes</i>)		Around the country between 200 and 800 m water depth.	Little is known about juvenile ling distributions below 40 cm, with juveniles appearing in trawl survey data at about 40 cm TL.	Little is known for New Zealand. Horn (2005) inferred large scale migrations for spawning, based on the presence of relatively discrete spawning grounds in different regions.	No information available.	Five stocks are suggested (Campbell, Chatham, Bounty, WCSI, and Cook Strait).	Horn (2005)
New Zealand sole (<i>Peltorhampus novaezeelandiae</i>)		Around the country in less than 50 m water depth.	Juveniles have been caught by trawlers in all areas where the species has been recorded.	No information is available.	No information available.	No information available.	Hurst et al. (2000a)
Red cod (<i>Pseudophycis bachus</i>)		Around the country but more common in the South. Found from 26–700 m.	Juvenile red cod can be found in waters off the continental shelf after summer spawning, in depths of 300–750 m. There are no known red cod nursery	No information is available.	No information available.	No information available.	Graham (1956), Habib (1975)

		grounds although juveniles have been caught in deep water after the spawning period.					
Red gurnard (<i>Chelidonichthys kumu</i>)		Around the country from 10–200 m.	Research trawl records show that 0+ and 1+ red gurnard (10–20 cm) are caught around much of the coast of the North Island in depths less than 100 m. High catches in Golden and Tasman Bays are thought to be evidence of a nursery which supplies the west coast of the South Island, where catches are dominated by older fish	Elder’s (1976) Hauraki Gulf study indicates that red gurnard make seasonal migrations associated with ontogeny and reproductive maturity, with fish moving into deeper water as they get older, and on a seasonal basis to spawn.	No information available.	Separate stocks are thought to exist, but their definitions are not clear.	Elder (1976)
Rig (<i>Mustelus lenticulatus</i>)		Around the country. Most common in shelf waters 100–200 m.	Young are either born in estuaries or large coastal harbours, or they make their way into these places after being born in nearby coastal waters.	Rig aggregate annually in spring and summer in shallow coastal waters to breed. Rig are highly mobile, undergoing seasonal inshore–offshore migrations, presumably relating to their reproductive cycle.	Large scale movements have been shown by tagging, with some fish moving up to 1159 km, and more than 50% fish having moved more than 50 km.	Several stocks are suggested. SPO 1 (Raglan through to East Cape), SPO 8 (Raglan to Wellington), SPO 2 (East Cape to Wellington), SPO 7 (South Island north and west coasts excluding Fiordland), and SPO 3 (South Island east coast, Southland and Fiordland).	Graham (1956) Francis (1988) Paul (2000) Francis (2010) Francis et al. (2012)
Rough skate (<i>Zearaja nasuta</i>)		Rough skate are endemic to New Zealand, and are abundant on the mid to outer continental shelf, and are more abundant around the South Island to depths of 500 m.	Rough skate less than 40 cm appear to be confined to depths less than 75 m.	Little information is available for either New Zealand species: but their broad distribution around New Zealand, and more specific nursery areas for egg-laying, suggests that seasonal reproductive movements occur.	A tagging programme is underway.	No information available.	Francis (1997c).
Smooth skate (<i>Dipturus innominata</i>)		Smooth skate are endemic to New Zealand, and are abundant on the mid to outer continental shelf throughout the mainland. They are found down to 700 m.	Smooth skate juveniles are found in waters less than 200 m depth.	Little information is available for either New Zealand species: but their broad distribution around New Zealand, and more specific nursery areas for egg-laying, suggests that seasonal reproductive movements occur.	A tagging programme is underway.	No information available.	Graham (1939b, 1956), O’Driscoll et al. (2003) Francis (1997c)
Sand flounder (<i>Rhombosolea plebeia</i>)		Around the country. Found to a depth of 100 m.	Juveniles are seasonally very abundant in sheltered estuaries and harbours, and have been recorded from many estuaries	There is no evidence of large distance migrations; migration consists of local offshore movement to spawn	Most tagged fish movements are local, but distances of up to 200 n.m. have been recorded.	Multiple stocks are suggested. East and south coast South Island; central New Zealand; west coast	Colman (1973, 1974, 1978)

			around New Zealand. Local estuary to adjacent coast movement has been shown.	in winter and spring, and of onshore movement in the summer.		South Island; Tasman Bay; east and west coasts of Auckland.	
School shark (<i>Galeorhinus galeus</i>)		Around the country, mostly less than 200 m but down to 800 m, also caught pelagically in waters more than 1000 m deep.	Preferred pupping grounds occur along shallow (usually sandy) coastlines or in harbours and estuaries. Well-defined nurseries have not been identified in New Zealand.	Movements of this species are complex and vary by size and sex. Like rig, this species commonly aggregates in inshore waters during warmer months and disperses across the shelf and upper slope during autumn and winter.	Tagging work shows large distance movements (hundreds of kilometres) to be common.	Large distance movements strongly suggest that school shark form one stock within New Zealand with significant mixing with the Australian stock.	Francis & Mace (1980), Seabrook-Davison et al. (1985), Stevens & West (1997), Hurst et al. (1999), Francis (2010)
Sea perch (<i>Helicolenus percoides</i> & <i>H. barathri</i>)		Occur around New Zealand. Found to a depth of 900 m.	Little is known about settlement and habitat requirements of juvenile sea perch.	No information available.	No information available.	Very little data relevant to stock boundaries currently exists for this species.	Paul & Francis (2002)
Silver warehou (<i>Seriotelella punctata</i>)		Around the country, but more common around the South Island and Chatham Rise. Found between 200 and 800 m.	Juvenile silver warehou have been reported over the continental shelf of the South Island, in particular on the Pegasus Bay shelf and the Canterbury Bight. Progression of juveniles into deeper waters of the continental slope with increasing size has been noted.	No information available.	No information available.	It is uncertain whether the same stock migrates from one area to another, spawning whenever conditions are appropriate, or if there are several separate stocks.	Paul (2000), Bruce et al. (2001a)
Snapper (<i>Pagrus auratus</i>)		Most abundant in the northern half of the North Island, but occurs throughout the west coast of North Island, east coast North Island to Hawkes Bay, as well as in Tasman, and Golden Bays, and the Marlborough Sounds in the South Island. Most commonly found in waters less than 70 m deep.	Juveniles more common inshore and structured estuarine habitats seem to be important for immediate post-settlement stage snapper. Juveniles probably leave estuaries/harbours after about 3–5 months and gradually disperse into deeper coastal waters as they get older.	There are a number of spawning aggregation sites throughout the area that snapper occupy. While not all snapper necessarily move to these aggregations for spawning, most snapper appear to undertake seasonal and potentially long distance movements to contribute to these aggregations (as evidenced by seasonal patterns in tagging and abundance).	Snapper movement is complex with tagging indicating a continuum of movement behaviour from highly residential (hundreds of metres) to highly mobile (hundreds of kilometres) present within the snapper stock. Movements seem to be influenced by seasonal spawning aggregations as well as habitat and location (inshore and reef habitats being more residential). Furthermore, snapper appear to be able to change their movement behaviour from mobile to residential, but potentially not in the other direction.	Multiple separate stocks are likely to exist: west coast North Island, east coast North Island, Hawkes Bay and South Island.	Cassie (1956), Paul (1976), Crossland (1977a, 1982), Kingett & Choat (1981), Drummond & Mace (1984), Gilbert & McKenzie (1999), Morrison et al. (2009), Parsons et al. (2009, 2011)
Spiny dogfish (<i>Squalus</i>)		Found around the country, but mainly	Inshore areas of the South Island, especially along the	Once maturity is reached fish undertake inshore/offshore	No information available. Movement data from overseas	No information available.	Graham (1956), Hanchet (1986,

<i>acanthias</i>)		around the South Island. Found between 10 and 900 m.	east coast of the South Island from Banks to the Otago Peninsula.	migrations associated with sexual reproduction. North/south migrations are also suggested.	shows great variation, including some resident and migratory components – there is also some suggestion of these in New Zealand.		1988), Carbines & Cole (2009)
Tarakihi (<i>Nemadactylus macropterus</i>)		All around New Zealand down to 400 m.	Vooren (1975) concluded that tarakihi nurseries were mostly some way offshore (10–30 km) in depths of 20–100 m and in a number of areas, also noted the presence of biogenic habitat. However, they also appear common on shallow rocky reefs along the lower east North Island and top of the South Island.	Movement in adult populations has received limited attention. Annala (1987) reported tagging studies carried out in various locations; while first year returns showed limited movement, fish at liberty for longer indicated more extensive migrations of over 300 km. Spawning migrations or ‘runs’ are well known to commercial fishers.	No information available.	Large-scale movements during both larval and adult phases and lack of genetic isolation suggest that tarakihi around New Zealand are a single stock.	Graham (1939b, 1956), Vooren (1972, 1975), Robertson (1978), Jordan (2001), Langley & Starr (2012)
Trevally (<i>Pseudocaranx dentex</i>)		Common around the North Island and the north-west of the South Island, mainly less than 100 m depth.	Juveniles are found in estuaries and harbours, and on some shallow water rocky reef systems, with an association with structure, e.g. subtidal seagrass, horse mussel beds, generally in higher current areas. Pelagic phase associates with drift algae.	Tagging data indicates some fish movement into shallow waters in spring, followed by a movement back into deeper waters in summer.	Tagging data shows relatively limited movement, with more than 50% of fish moving less than 18.5 km; but with long distance movements up to 246 km. Adult trevally show both pelagic and demersal distribution patterns, and can form large schools in the water column and on the surface. Tagging suggests that these patterns reflect different seasonal behaviours of the same stock.	Stock structure is poorly understood; but several discrete stocks are likely.	James (1984), Horn (1986), Walsh et al. (2010)
Trumpeter (<i>Latris lineata</i>)		More common in the south, in waters 50–200 m.	Australian trumpeter initially settle on inshore reefs (at depths of about 5 m) at the end of their long postlarval period, where they remain for several years, until they reach maturity and migrate into deeper areas. New Zealand fish are expected to follow a similar behaviour.	Little is known about the larger scale migratory patterns of New Zealand trumpeter. Australian research has identified that some adults are highly migratory (100s–1000s km scales).	No information available.	No information available.	Chadderton & Davidson (2003), Morton et al. (2005), Tracey & Lyle (2005), Tracey (2007)
Yellowbelly flounder (<i>Rhombosolea leporina</i>)		Estuaries, embayments and shallow coastal regions (to a depth of 50 m) around the country.	Juveniles appear to be exclusively limited to sheltered harbours and estuaries and have been found in many estuaries around New Zealand.	Yellowbelly flounder adults move offshore to spawn between winter and spring, followed by a movement back onshore.	No information available.	No information available.	Tunbridge (1966a), Colman (1973, 1974, 1976), Francis et al. (2005, 2011)
Yellow-eyed		Around the country,	Juveniles are a ubiquitous and	No information available	No information available.	No information available.	Kingsford &

mullet (<i>Aldrichetta forsteri</i>)		but more common in the north. Found from the surface down to 50 m.	cosmopolitan component of most estuarine fish assemblages, and are found universally across New Zealand estuaries.				Tricklebank (1991), Taylor & Paul (1998). Curtis & Shima (2005) Francis et al. (2005, 2011)
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