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Review of productivity parameters and stock assessment options for kingfish (*Seriola lalandi lalandi*)

New Zealand Fisheries Assessment Report 2014/04

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EXECUTIVE SUMMARY

McKenzie, J.R. (2014). Review of productivity parameters and stock assessment options for kingfish (*Seriola lalandi lalandi*)

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Results of yield per recruit and spawning stock biomass per recruit (YPR/SSBR) analyses are presented and discussed. Modelling options for obtaining sustainable yield estimates for kingfish stocks range from simple biomass dynamic models to fully age and length structured models with multiple gear-specific fishing mortalities. The utility of these approaches for kingfish stock assessment and management are reviewed in this report.

MPI established 40% SSB/R as a target B_{MSY} proxy for kingfish in 2013, this being consistent with international best practice for a medium productivity species. YPR fishing mortality (F) estimates that achieve a 40% SSB/R ($F_{40\%}$; MPI 2011) were calculated by varying the age/size at first harvest under the assumption that fishing mortality (F) was acting uniformly after the age/size of first selection. Although the optimum YPR strategy equated to a high F applied after the age 14, the potential gains in yield under this strategy are minimal relative to those achievable under the current recreational and commercial minimum legal size (MLS) limits. With the current levels of recreational and commercial MLS the range in fishing mortality likely to achieve the 40% SSB/R target for kingfish ($F_{40\%}$) is 0.10–0.12; equating to a total mortality (Z = M + F) across all age classes older than 5–7 years in the order of 0.3. As neither the commercial nor recreational kingfish fisheries appear to be uniformly selective across all sizes and ages above their respective values of MLS, greater yields from both fisheries could be achieved through bringing the selectivity characteristics of these fisheries (in particular commercial trawl) more into line with this YPR requirement.

Estimates of total mortality (Z) derived using catch curve analyses of recent age data collected from a uniformly selectivity fishery (i.e. recreational line) can be used to assess the status of the fishery relative to $F_{40\%}$ SSB/R target. The $F_{40\%}$ approach is relatively cost effective when compared to other, more expensive approaches such as length and age population modelling, and is therefore currently the best stock assessment and monitoring option for kingfish given the moderate to low relative value and importance of the fisheries.

An understanding of stock boundaries is a common requirement across all kingfish assessment options making this a high kingfish research priority in the immediate future.

1 INTRODUCTION

Kingfish became a quota species under the QMS in October 2003. Kingfish TACCs were established relative to seven administrative Quota Management Areas (Figure 1). Although this report refers to these areas as "stocks" kingfish biological stock boundaries have yet to be established (Walsh et al. 2003; Smith et al. 2004).

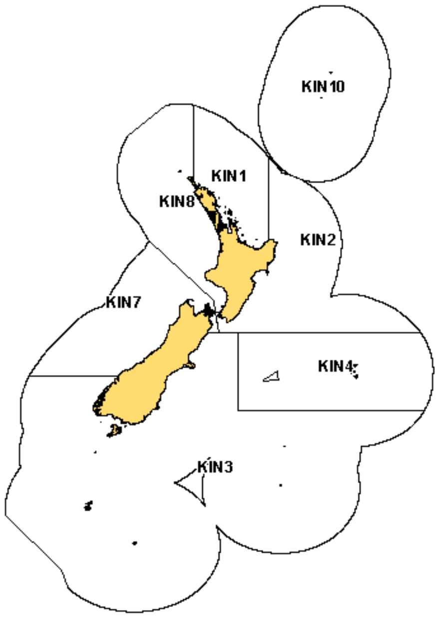

Figure 1: Kingfish Quota Management Areas as of October 2003.

Significant numbers of kingfish are taken in KIN 1, KIN 2 and KIN 8 (Figure 1) the other four QMAs are irrelevant from a fisheries management perspective.

Relative to other species the annual commercial catch of kingfish is low, now constrained under quota to be 200 tonnes per annum (Sullivan et al. 2005). However, kingfish has a high value per kilogram, and indications are that the market demand for kingfish greatly exceeds current commercial catch levels.

Kingfish is predominately taken as by-catch in snapper, trevally, and tarakihi fisheries; less then 1% of the annual reported catch is targeted (Walsh et al. 2003; McKenzie et al. 2014a). The main methods catching kingfish are trawl, setnet and longline (Walsh et al. 2003; McKenzie et al. 2014a). Kingfish was introduced into the Quota Management System (QMS) in October 2003; Total Allowable Commercial Catch (TACC) limits were set significantly below historical average catches. The by-catch nature of the commercial kingfish fishery makes it difficult to sample for length and age. Kingfish landings tend to be small and widely dispersed (McKenzie et al. 2014a).

Based on recreational survey information, the annual non-commercial kingfish catch may be twice the level of commercial catch (Walsh et al. 2003; Boyd et al. 2004). Kingfish is an important recreational game-fish species; it is predominantly caught by line fishing. Significant numbers of kingfish are taken each year by charter boats (James et al. 1997).

Recent research undertaken by NIWA has improved our understanding of kingfish growth, natural mortality, stock separation, fecundity and size-at-maturity (McKenzie et al. 2014b; Smith et al. 2004; Francis et al. 2005). Using results from these studies it is now possible to derive "per-recruit" type equilibrium reference points for kingfish, i.e. Yield Per-Recruit (YPR) & Spawning Stock Biomass Per-Recruit (SSB/R).

This report is one of a series of five kingfish assessment and management reports produced for the then Ministry of Fisheries between 2000 and 2006. An outline of the content and scope of each report in chronological order of writing is as follows:

1. *Information available for the management of New Zealand kingfish stocks.* (Walsh et al. 2003)

This report summarises what was known about kingfish biological and life history of New Zealand as well as providing a summary of New Zealand kingfish management and monitoring up to the year 2000. A range of assessment and monitoring options are also discussed and evaluated.

2. *Kingfish stock structure* (Smith et al. 2004)

This report provides an evaluation of information available to spatially delineate different New Zealand kingfish stocks. The report also contains results from a pilot study to assess the utility of meristic and parasite markers in kingfish stock delineation.

3. *Age, growth, maturity and natural mortality of New Zealand kingfish* (McKenzie et al. 2014b)

A range of growth estimates (von Bertalanffy) for kingfish derived using age and length data collected from the eastern Bay of Plenty charter-boat fishery, and growth increment data derived from tagging studies, are presented. The charter-boat data is also used to derive a total mortality (Z) estimate for the eastern Bay of Plenty and a revised estimate of natural mortality (M). The report also includes a review of kingfish ageing methods and a reanalysis of the available maturity at-age data.

5. *Review of stock monitoring options for kingfish* (McKenzie et al. 2014a)

The feasibility of monitoring kingfish stocks using recreational and commercial catch data is examined. Specifically considered are the collection of catch and effort data, age and length data, tag recovery information, and parasite identification.

4. *Review of productivity parameters and stock assessment options for kingfish* (this report)

Results of yield per recruit and spawning stock biomass per recruit (YPR/SSBR) analyses are presented and discussed. Modelling options for obtaining sustainable yield estimates for kingfish stocks range from simple biomass dynamic models to fully age and length structured models with multiple gear-specific fishing mortalities. The utility of these approaches for kingfish stock assessment and management are reviewed.

2 KINGFISH PRODUCTIVITY PARAMETERS

2.1 Growth

Growth parameters (von Bertanlaffy) were derived for kingfish using length/age and tagging data collected in the eastern Bay of Plenty and east Northland (McKenzie et al. 2014b).

An investigation of the first annual band using daily ring counts was undertaken by Francis et al. (2005). However due to the paucity of otolith material Francis et al. failed to identify the first annual ring conclusively. Francis (pers comm) believes daily ring counts still offer an option for validating growth. If ageing becomes integral to future kingfish stock monitoring possibly the daily growth work should be repeated using a larger number of otoliths.

There is some evidence that growth in male and female kingfish differs but growth analyses have failed to show this conclusively (McKenzie et al. 2014b).

2.2 Natural mortality

The New Zealand and Australian ageing work suggests that very few kingfish live longer than 24 years (McKenzie et al. 2014b; Gillanders et al. 1999a; Stewart et al. 2001) The Hoenig (1983) ratio for a maximum observed age, 24 years equates to a natural mortality (M) rate of 0.19.

A catch curve analysis using lightly exploited age cohorts (13+) by McKenzie et al. (2014b) is based on an estimated M of 0.25. It is doubtful that M could be refined further from the current observational data, and possibly would be better estimated within the context of a stock assessment model.

2.3 Length/age at first maturity

Poortenaar et al. (2001) examined gonad condition in a large number of kingfish collected from west and east coast trawl landings. Based on length-at-maturity observations collected during the peak spawning period (October to January) Poortenaar et al. calculated that the lengths-at-50%-maturity in male and female kingfish were 81 and 94 cm respectively. The length-at-50%-maturity estimates were revised by McKenzie et al. (2014b) using the Poortenaar et al. data; resulting in 83 cm for males and 97 cm for females. A study conducted on New South Wales kingfish produced significantly smaller length-at-50%-maturity estimates: 36 cm for males and 70 cm for females (Gillanders et al. 1999b). Gillanders et al. estimated that the ages for kingfish of these lengths were 0+ for males and 3+ for females. Kingfish in the Poortenaar et al. study were not aged, hence age-at-50%-maturity cannot be derived directly for their data. Indirect estimates using the growth rates published in McKenzie et al. (2014b) put the age at 50% maturity at 8+ and 10+ for males and females respectively. Poortenaar et al. suggest that differences in age and length at maturity between Australian and New Zealand kingfish might be due to different growing conditions or behavioural and physiological differences between populations.

2.4 Fecundity

Information on kingfish spawning and fecundity largely comes from aquaculture. Under aquaculture conditions a reproductively active female kingfish will spawn on average every two days. Captive 100+ cm female kingfish have been observed to release in the order of 650 000 eggs per spawning event (NIWA unpublished data). Poortenaar et al. (2001) showed that wild kingfish spawn during the months November to January. The overall conclusion is that kingfish, typical of most teleosts, are capable of high reproductive output. The survival of kingfish larvae is likely to be subject to environment variation and therefore recruitment success is probably not strongly linked to stock size.

3 FISHING MORTALITY AND SELECTIVITY

3.1 Selectivity

Kingfish is taken predominantly by trawl, setnet, longline, and recreational line (McKenzie et al. 2014b). The selectivity characteristics of these methods are unknown for kingfish. The limited catch sampling data available indicates that the selectivity characteristics of trawl and recreational line fishing are likely to differ substantially (Figure 2). Trawl length data collected at sea in 1999 from the Bay of Plenty were predominantly less than 100 cm whereas 100 cm corresponded to the mode of the size composition of charterboat catches in 2002 (Figure 2).

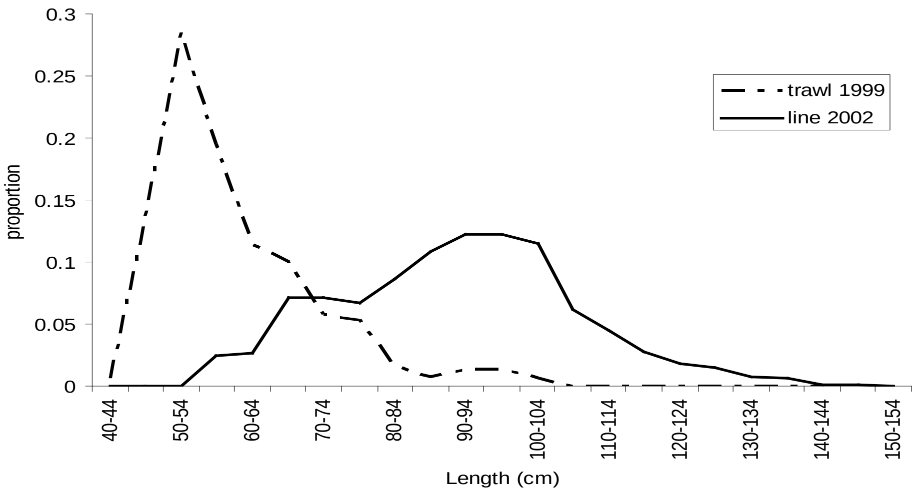

Figure 2: Length frequencies of kingfish taken in the Bay of Plenty by single trawl (Walshe & Akroyd 1999) and recreational line (charter boat data 2002; McKenzie et al. 2014b).

Although there is no comparable length data available for setnet fishing, the selectivity characteristics of the method are typically domed (Hovgård & Lassen 2000) it is therefore likely that this method poorly samples older kingfish in the population.

Gear specific selectivity estimates would be required for future kingfish stock assessments. In order to provide a basis for estimating selectivity, some level of catch sampling would be required from all major kingfish fishing methods.

3.2 Catch history

Reliable estimates of commercial kingfish harvest by method are available back to 1983 (Walsh et al. 2003; McKenzie et al. 2014a). Although pre-1983 catch records are available they are fragmented and unreliable. The commercial harvest from KIN 1 has been the largest of the three main QMAs. Annual KIN 1 catches since 1983 have never exceeded 400 t and in the nine years after 1996 have been substantially below 200 t. The current TACC for KIN 1 is 91 t. Kingfish is a relatively small fishery compared to other inshore fisheries (e.g. snapper, kahawai, trevally, tarakihi, red gurnard, and John Dory). Although historical targeting has occurred, kingfish is essentially a bycatch species in commercial fisheries (Walsh et al. 2003; McKenzie et al. 2014a).

Despite being an important recreational species, recreational catch levels are poorly understood (Walsh et al. 2003). Evidence from diary surveys suggest that recreational harvest levels in KIN 1 may have been as high as 400 t in recent years (Sullivan et al. 2005).

4 YIELD PER RECRUIT

4.1 Introduction

Assuming that growth and natural mortality rates are reasonably well understood, yield-per-recruit (YPR) analysis provides a useful means to derive optimum harvest strategies in fisheries (Beverton & Holt 1957). Using the classical Beverton and Holt YPR approach it is possible to determine what level of fishing mortality in relation to age will maximise yield (harvest weight) per recruit under assumptions of uniform growth, natural mortality and selectivity. It should be realised however that the YPR surface on its own gives no indication as to what a sustainable harvest strategy would be, i.e. fishing mortality levels that optimise YPR are not necessarily sustainable, as stock recruit relationships are not taken into account.

Typically YPR surfaces are interpreted relative to predefined Biological Reference Points (e.g. $F_{0.1}$: the fishing mortality corresponding to point on the YPR curve where the slope is 10% of that at the origin), and there are many other variations (Sissenwine & Shepherd 1987; Caddy & Mahon 1995; Schnute & Richards 1998). Probably the most useful BRPs are those based on Spawning Stock Biomass per recruit ratios. SSB/R is the total biomass of mature fish (typically females) per recruit summed over all years the cohort is observed in the population. The SSB/R is typically expressed as a percentage of the unexploited SSB/R, e.g. 20% SSB/R_{Fzero}(Williams & Shertzer 2003). There are no definitive rules for setting SSB/R reference points. These are usually agreed to by fisheries managers or working groups with regard to the underlying dynamics of the stock in question (Caddy & McGarvey 1996). Fishing mortalities that maintain a stock at 40% SSB/R may involve risk if recruitment and growth variability is high or if recruitment is highly dependent on stock size. Stocks where these factors do not feature strongly may be sustainable at 20% SSB/R (Clark 1993; Mace 1994; Brodziak 2002; Dorn 2002; Caddy 2004).

In New Zealand most stocks are assessed and managed relative to three reference points (MPI 2011):

1. The hard limit: if this limit is breached, the fishery will be closed unit at least the soft limit is attained with 70% certainty.
2. The soft limit: if this limit is breached, a formal rebuilding plan must be implemented.
3. Target: the optimum stock size, this ideally being B_{MSY}, but in the absence of a robust B_{MSY} estimate a suitable B_{MSY} proxy reference point may be used.

The MPI introduced limit reference points for kingfish in 2013 corresponding to 10% B_0 (hard); 20% B_0 (soft) and a 40% SSB/R target which MPI deems is comparable to 35% B_0 in turn either of these reference points can be used as proxies for B_{MSY} (MPI 2011).

4.2 Methods

Growth and mortality estimates provided in the reports by McKenzie et al. (2014b) and Walsh et al. (2003) were used to derive YPR isopleths (Table 1).

Natural mortality (M) rates for New Zealand kingfish stocks are not well determined. Estimates provided in McKenzie et al. (2014b) suggest that 0.18–0.25 is a plausible range for M. YPR surfaces were generated relative to three assumed rates of M (Table 1).

Table 1: Parameters used to derive kingfish YPR isopleths.

Natural Mortality		Growth parameters (female)			Length weight ($wt = aL^b$)	
M	F	K	L_{inf}	t0	a	b
0.18	0 - 0.80	0.096	140.58	-1.34	0.0365	2.762
0.2	0 - 0.80	0.096	140.58	-1.34	0.0365	2.762
0.25	0 - 0.80	0.096	140.58	-1.34	0.0365	2.762

YPR surfaces were calculated over a fishing mortality range from 0 to 0.80 and an age at first exploitation range from 1 to 12 years. Fishing mortality rates were applied uniformly over all age classes, this is analogous to uniform selectivity. The YPR summations were based on a cohort age range of 0 to 25 years inclusive.

SSB/R (females) was calculated as the summation of the total weight of all mature cohorts up to age 25 assuming the 'knife-edged' age at first maturity is 10[1] years.

4.3 Results

Under high natural mortality scenarios less biomass per recruit is available for exploitation in subsequent years; consequently kingfish model runs with higher M are less productive in YPR terms (Figure 3).

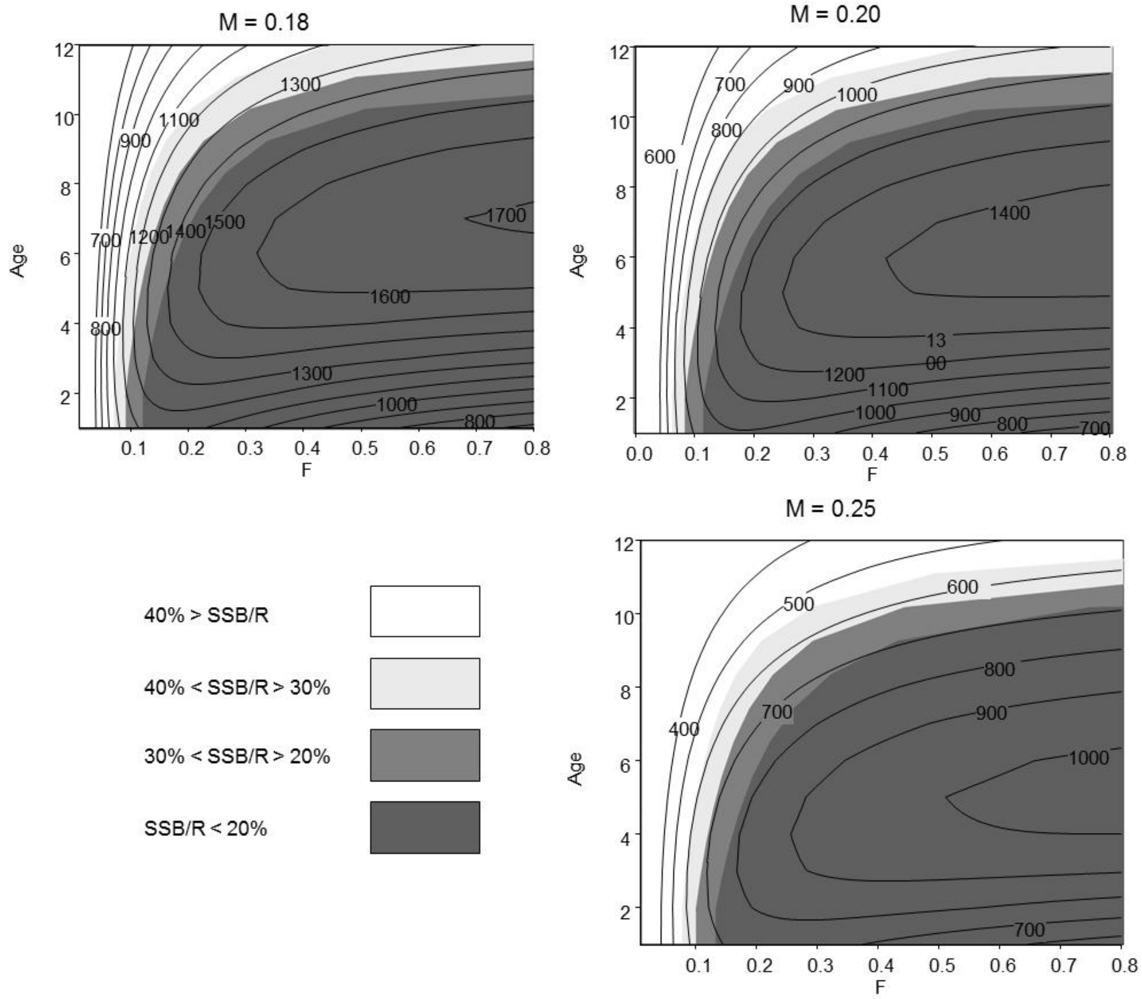

Figure 3: YPR and SSB/R response surfaces for under 0.18, 0.20, 0.25 natural mortality rates. YPR isopleths are labelled in grams.

Similarly, the age-at-first-recruitment that maximises YPR (F_{max}) is younger at higher assumed levels of M; being 7–8 years for M = 0.18 and 5–6 years for M = 0.25 (Figure 3; Table 2)

[1] This is the age for females corresponding to the mean length-at-50%-maturity, i.e. 93 cm at 10 years (McKenzie et al. 2014b). As it is assumed that all female kingfish younger than 10 years are immature the SSB/R curves are therefore conservative.

Table 2: Age at selection and fishing mortalities that maximise YPR (female) at varying assumed levels of M.

BRP	F	U	YPR g	%SSB/R	age	length cm	M
20%SSB/R	1.16	70%	1481	20%	11	98	0.18
30%SSB/R	1.10	70%	1360	30%	12	102	0.18
40%SSB/R	66.00	100%	1224	40%	14	108	0.18
Fmax	-	-	1744	< 1%	8	83	0.18
$F_{0.1}$	0.19	20%	1433	20%	6	71	0.18
20%SSB/R	1.58	80%	1196	20%	11	98	0.2
30%SSB/R	1.79	80%	1091	30%	12	102	0.2
40%SSB/R	1.68	80%	974	40%	13	108	0.2
Fmax	4.26	100%	1489	< 1%	7	77	0.2
$F_{0.1}$	0.21	20%	1227	18%	6	71	0.2
20%SSB/R	0.19	20%	790	20%	5	64	0.25
30%SSB/R	0.13	10%	688	30%	5	64	0.25
40%SSB/R	0.10	10%	589	40%	5	64	0.25
F_{max}	10.31	100%	1063	< 1%	6	71	0.25
$F_{0.1}$	0.25	20%	875	12%	5	64	0.25

For M ranging between 0.18 and 0.20 the 20, 30 and 40% SSB/R optimum fishing mortalities are similar (over 70% annual removal (U); Table 2) as are the optimum ages of first exploitation (11–14 years; Table 2). The optimum harvest strategy relative to the 20, 30 and 40% SSB/R shifts toward taking fish at a younger age (5–6 years; Table 2) and at a lower exploitation rate (10–20% annual removals; Table 2) when M is closer to 0.25.

The region on the YPR surfaces where F_{max} and $F_{0.1}$ occurs is below the 20% SSB/R isopleths for all three levels of M (Figure 3; Table 2). These BRPs are not conservative and are not likely to be appropriate for kingfish.

Although the optimum YPR strategy calls for high exploitation after the age of 14, only marginal gains (less than 10%) in YPR are likely to be achieved by shifting the current minimum legal size (MLS) for recreational (75 cm age 6.5 years) and commercial (65 cm 5.0 years) to 100–108 cm (12–14 years), assuming selection is uniform after this size/age (Table 3). The current values of recreational and commercial MLS both equate to an $F_{40\%}$ of 0.10–0.12 over the plausible range of M (Table 3) i.e. an annual exploitation level (U) of approximately 10% for all likely values of M (Table 3).

Table 3: Fishing mortalities that maximise YPR (female) at varying assumed levels of M relative to optimum (Table 2) for: a. recreational MLS (75 cm age 6.5) b. commercial MLS (65 cm age 5)

a.

BRP	F	*U	YPR g	%SSB/R	M	% of optimum YPR (Table 2)
20%SSB/R	0.20	20%	1439	20%	0.18	97.15%
30%SSB/R	0.14	10%	1282	30%	0.18	94.26%
40%SSB/R	0.10	10%	1117	40%	0.18	91.20%
Fmax	1.21	70%	1713	< 1%	0.18	98.22%
$F_{0.1}$	0.20	20%	1432	20%	0.18	99.97%
20%SSB/R	0.21	20%	1196	20%	0.2	100.00%
30%SSB/R	0.15	10%	1058	30%	0.2	96.95%
40%SSB/R	0.11	10%	917	40%	0.2	94.17%
Fmax	2.21	90%	1483	< 1%	0.2	99.54%
$F_{0.1}$	0.22	20%	1217	18%	0.2	99.14%
20%SSB/R	0.24	20%	768	20%	0.25	97.16%
30%SSB/R	0.17	20%	670	30%	0.25	97.34%
40%SSB/R	0.12	10%	574	40%	0.25	97.54%
F_{max}	-	-	1060	< 1%	0.25	99.79%
$F_{0.1}$	0.30	30%	828	14%	0.25	94.64%

b.

BRP	F	*U	YPR g	%SSB/R	M	% of optimum YPR (Table 2)
20%SSB/R	0.16	20%	1404	20%	0.18	94.79%
30%SSB/R	0.12	10%	1253	30%	0.18	92.09%
40%SSB/R	0.09	10%	1091	40%	0.18	89.12%
Fmax	0.55	40%	1624	1%	0.18	93.12%
$F_{0.1}$	0.17	20%	1418	19%	0.18	98.96%
20%SSB/R	0.17	20%	1183	20%	0.2	98.94%
30%SSB/R	0.12	10%	1047	30%	0.2	95.92%
40%SSB/R	0.09	10%	907	40%	0.2	93.13%
Fmax	0.73	50%	1420	< 1%	0.2	95.33%
$F_{0.1}$	0.19	20%	1224	17%	0.2	99.74%
20%SSB/R	0.19	20%	790	20%	0.25	99.91%
30%SSB/R	0.14	10%	688	30%	0.25	99.90%
40%SSB/R	0.10	10%	588	40%	0.25	99.90%
F_{max}	1.73	-	1048	< 1%	0.25	98.66%
$F_{0.1}$	0.26	20%	873	12%	0.25	99.84%

* Annual exploitation (U) rounded to nearest 10%

The YPR isopleths (Figure 3) assume uniform selectivity after age of first selection; if the selectivity characteristics of the fishery are non-uniform the maximum YPR from the fishery will be less than the optimum (Table 3). The selectivity characteristics of the three principal kingfish targeting methods (bottom trawl; set net; line) are not well determined. Catch at-age sampling of the Bay of Plenty charter-boat fishery shows that experienced fishers fishing the more off-shore areas of the Bay catch a broad range of length/age classes (Figure 2; McKenzie et al. 2014b). Assuming that this is indicative of catching patterns of recreational kingfish fisheries generally, the fishery as a whole is likely to be uniformly selective after the optimum YPR length (100–108 cm) and relatively less selective at lengths smaller than this (Figure 2). The available trawl catch sampling data for kingfish (Figure 2) indicates that maximum selectivity occurs around 55 cm (3 years) – the absence of a long right hand tail as seen in the recreational data would imply that trawl selectivity is more likely to be domed, i.e. poorly selective of older/larger kingfish.

4.4 Discussion

If the goal is to achieve optimum yield (harvest) from kingfish stocks, the underlying natural mortality rate strongly influences the minimum size/age at which fishing exploitation should occur. The higher the natural mortality rate the younger age of first-exploitation should be. The choice of biological reference point on the YPR curve is the critical factor determining optimum fishing mortality levels for kingfish. The YPR at 20%SSB/R is approximately 2 times greater than at 40%SSB/R, and this ratio varies little over the assumed range of M. Higher yields are achieved against the more traditional $F_{0.1}$ and F_{max} reference points, however these equate to SSB/R reductions well in excess of 80%. The fishing mortalities that correspond to $F_{0.1}$ and F_{max} are unlikely to be sustainable for kingfish, as they do not account for a stock recruit relationship.

MPI established 40% SSB/R as a target B_{MSY} proxy for kingfish in 2013, this being consistent with international best practice for a medium productivity species. In this report YPR fishing mortality (F) estimates that achieve a 40% SSB/R ($F_{40\%}$; MPI 2011) were obtained by varying the age/size at first harvest under the assumption that fishing mortality (F) is acting uniformly after the age/size of first selection. Although the optimum YPR strategy equated to a high F applied after the age 14, the potential gains in yield under this strategy are minimal relative those achievable under current recreational and commercial minimum legal size (MLS) limits. With the current values of recreational and commercial MLS the range in fishing mortality likely to achieve the 40% SSB/R target for kingfish ($F_{40\%}$) is 0.10–0.12; equating to a total mortality (Z = M + F) across all age classes older than 5–7 years in the order of 0.3. As neither the commercial or recreational kingfish fisheries appear to be uniformly selective across all sizes and ages above their respective MLS, greater yields from both fisheries could be achieved through bringing the selectivity characteristics of these fisheries, in particular commercial trawl, more into line with this YPR requirement,.

5 STOCK BOUNDARIES

The number of biological stocks and stock boundaries are not well understood for New Zealand kingfish. No significant genetic differences were found among kingfish samples from New South Wales and the east coast of the North Island (Nugroho et al. 2001). Yet tagging movements suggest that adult kingfish remain in the same general area of release with only 3% of all fish recovered having moved more than 100 kilometres from the release point (Holdsworth & Saul 2005). However, due to the lack of spatial information on recreational angler effort, the tagging information is difficult to interpret. A recent study by Smith et al. (2004) using a combination of parasite and meristic techniques found evidence for separating east and west coast kingfish populations. The parasite data also suggested a possible stock boundary between the Bay of Plenty and the Wairarapa coast. Due to the limited number of samples collected the Smith et al. findings do not constitute definitive proof of stock separation. The authors however believe the techniques do have stock separation utility for kingfish and that more data should be collected.

6 STOCK ABUNDANCE

An evaluation of stock monitoring options for kingfish and a review of data available for stock assessment is presented in McKenzie et al. (2014b). The authors concluded that the quantity and quality of setnet CPUE data may be sufficient to track kingfish stock abundance back to 1989. However, due to recent declines in the use of the method they believe setnet CPUE is unlikely to be viable option for future stock monitoring and recreational CPUE may be a viable alternative. McKenzie et al. suggest that the collection of age and length information from KIN 1 was feasible on an ongoing basis.

7 KINGFISH STOCK ASSESSMENT OPTIONS

7.1 Maximum Sustainable Yield

The Fisheries Act (1996) defines Total Allowable Catch in terms of Maximum Sustainable Yield (MSY). MSY is the maximum harvest that can be removed from a stock that does not result in a net change in its total biomass. MSY has strict mathematical definitions in the fisheries literature, most of these are deterministic (see Ricker 1975). However MSY in terms of the New Zealand Fisheries Act is not strictly defined. Consequently the Ministry of Fisheries found it necessary to develop its own management definitions for MSY – these being Current Annual Yield (CAY) and Maximum Constant Yield (MCY). CAY is the maximum sustainable yield that can be taken from a fishery when the start-of-year biomass is known. The CAY strategy accounts for the fact that even stable populations fluctuate in size due to natural variation in recruitment and growth processes; as the starting year biomass varies so does CAY. The alternative strategy is to manage in respect to average annual yield such that in any given year there is a 50% probability of the CAY being below this level. This is in essence the MCY strategy; however the Ministry of Fisheries have added a risk contingency to the definition such that the MCY must lie below the CAY average. The Ministry of Fisheries provides a set of stock assessment derivations for CAY and MCY in the forward of the annual stock assessment plenary documents (e.g. MPI 2013). Although there is a requirement to express all stock assessments in terms of CAY or MCY, the plenary derivations are by no means the only definitions available to fisheries Working Groups.

The difficulty with managing in accordance to a CAY strategy is that for most New Zealand fish stocks start-of-year biomasses are not known with any certainty. Kingfish fits into this category. Even given a large investment in stock monitoring and stock assessment the long term prognosis is that for this reason, CAY management is not an option for kingfish.

By in large the management goal for species subject to the Quota Management System is either to maintain a stock at a biomass that will achieve MSY or move the stock toward this biomass. There has been no indication from the Ministry of Fisheries that their management objectives for kingfish are anything other than yield based. However in light of the 2003 TACC decisions which effectively capped commercial exploitation in all three stocks at historically low levels in the face of potentially burgeoning recreational catches a yield based approach to kingfish management may not suffice in the future. For example, recreational fishers may prefer that kingfish stocks be dominated by larger, older fish. The need to manage kingfish on criteria other than yield has ramifications for stock assessment; it may be necessary not only to manage stock-size and yield but age composition as well.

7.2 Yield based on average catch

In the absence of any formal modelling estimates of surplus production the Ministry of Fisheries preference was to estimate MCY as an average of historical catches from a period where there was no obvious change in catch per unit effort (Sullivan et al. 2005). The rationale was that catches from these years correspond to a period of stable biomass in the fishery and are therefore sustainable. Kingfish MCY estimates derived by this method are provided in the 2005 kingfish Working Group report (Sullivan et al. 2005). The validity of these estimates is however questionable. Over the period chosen to derive average catch (1984 – 1993): no stock abundances indices were available; annual commercial catches varied significantly in all stocks; and recreational harvest levels were unknown.

This approach is not recommended as a harvest setting option for kingfish. Aside from difficulties in defining stable periods in the stock history, harvest levels corresponding to a period of stable biomass do not necessarily correspond to the MCY.

7.2.1 Stock reduction analysis

Stock reduction analysis assumes the population is closed. It also requires that the total annual removals from the fishery are known and that an annual measure of CPUE is available for all years that the fishery has been operating (Hilborn & Walters 1992). Given that these factors are reliably known it is possible to estimate the initial biomass of the population before fishing began i.e. its unexploited or virgin biomass (B_0) and tracking forward from that the biomass in subsequent years. Due to the uncertainty surrounding historical recreational catch and the long history of exploitation, stock reduction is unlikely to be an assessment option for kingfish.

7.2.2 Virtual population analysis (cohort analysis)

Using Virtual Population Analysis (VPA) the biomasses of the individual cohorts that make up the fishery can be estimated for each year they appears in the fishery. VPA is essentially a hind casting technique whereby the individual cohorts are sequentially tracked through a series of annual catch at-age samples. Given that the annual catch of the cohort is known for each year it has been observed, given also that natural mortality is known, it is possible to derive an estimate of the cohort size for each year it was observed (Hilborn & Walters 1992). As a minimum, VPA requires an equivalent number of years of catch at-age samples as there are cohorts in the fishery. For kingfish this would be at least a fifteen year series and then only the stock biomass 15 years previous would be known with any certainty. Methods are available to tune a VPA and so derive more recent estimates of stock size. These largely involve calculating future fishing mortalities for the cohorts that still remain in the fishery. There are problems in doing this particularly if catchability (q) is changing, and the technique relies on having a very good measure of fishing effort (Hilborn & Walters 1992). Due to the intensive catch monitoring requirements VPA is not likely to be a practical option for kingfish stock assessment. If a 15 year catch-at-age time series was obtained for a kingfish stock the data would be likely to have greater stock assessment utility as input to a fully age-structured SA model than in a VPA.

7.2.3 Biomass survey

Selectivity issues and the predominately pelagic distribution mean that kingfish stocks cannot be reliably assessed from trawl surveys.

Results from recreational tagging programmes indicate that kingfish are amenable to assessment by mark-recapture (Holdsworth & Saul 2005). Seber (1982) provides tables whereby the number of tagged animals required to obtain population estimates of suitable precision can be derived. Based on the likely annual kingfish catch and the probable order of stock size, the Seber tables indicate that at least 10 000 kingfish would need to be tagged in each stock. The logistical and cost issues associated with conducting a kingfish tagging programme of the necessary scale mean that mark-recapture is unlikely to be a viable stock assessment option.

7.3 Surplus production analysis

Under surplus production assessment the stock is considered solely as undifferentiated biomass in that age/size structure is effectively ignored and the effects of recruitment, growth and mortality are pooled into a single production function (Haddon 2001). The information requirements for surplus production analysis are a time series of relative abundance and associated catch data. These methods require that the abundance index (typically CPUE) is tracking abundance in a truly proportional way and a marked change in abundance occurred in the data series, i.e. the abundance index series has sufficient contrast

(Hilborn & Walters 1992). Surplus production techniques do have potential for kingfish stock assessment and should not be discounted. McKenzie et al. (2014a) suggest that there may be CPUE utility in the time series of commercial setnet data collected between 1989 and 2004. Assuming that there is sufficient contrast in this series a stock production analysis may be feasible. However, given the likely dome-shaped selectivity of set net this method/fishery is likely only to target young fish and therefore its utility for representing changing abundance in the full adult stock is questionable. Also, there would be a need to estimate recreational harvest over the assessment years (note that this would also be a requirement for age-structured assessment techniques). There has been a general trend in the fisheries world to move away from surplus production methods when age information is available. Age-structured models arguably provide more robust assessments because the productivity processes of growth mortality and recruitment can be modelled explicitly.

7.4 Fully age/length structured assessment

Although age/length structured stock assessment methods model stock productivity more explicitly the disadvantage is that their information requirements are high. These modelling approaches track annual biomass as a set of length/age cohorts. Annual harvest is apportioned across the cohorts by a selectivity function. Cohort transitions are modelled in accordance with natural mortality, growth and recruitment (Megrey 1989).

7.4.1 Age based models

Recent growth studies conducted by NIWA indicate that it should be possible to derive an age-structured profile of kingfish fisheries (McKenzie et al. 2014b; Francis et al 2005; McKenzie et al. 2014a). Uncertainty still remains as to whether annual samples of catch-at-age data can be cost-effectively obtained for each kingfish stock. McKenzie et al. (2014a) concluded that the recreational fishery was likely to be the best source of this information. The number of years of catch-at-age observations required before a stock assessment can be done, is uncertain. Drawing parallels with other inshore species such as trevally (McKenzie 2008) the likely minimum number of years in the series would be between three and five.

The selectivity characteristics of the main fishing methods are not well understood. Some level of catch sampling would be required from each fishing method in order to estimate selectivity parameters.

7.4.2 Length based models

Length based models are implicitly age-structured in that changes in population length composition are usually modelled annually. The essential difference between length and age based models is that the observational information collected from the fishery is a length composition. The annual progress of length cohorts is governed by a growth function. The processes of natural mortality, annual harvest, and recruitment work in much the same way as in the age-based model. Selectivity is equally important but is defined in respect to length. Length based models are highly reliant on good growth estimates being available (Breen et al. 2000); some models incorporate raw growth data usually in the form of length specific annual increments (Watson et al. 2005).

Given that it may prove difficult or expensive to obtain catch at-age information from kingfish stocks, length based modelling approaches may be a viable alternative. One strong factor in favour of using length based approaches for kingfish is the large amount of growth increment data available from the long running recreational tag and release programme (Holdsworth & Saul 2005).

7.4.3 Length-age based models

Changing growth and recruitment patterns may be better accounted for by age-length models. The basic difference between this approach and the preceding two is that the stock is modelled as an age-length matrix rather than with vectors of length or age. Age-length models have not been used to assess any New Zealand stock. However, the approach has been investigated for snapper by Davies et al. (2002). Despite having 12 year series of age and length data for the model inconsistencies in some of the model fits led to further work on the approach being deferred (Davies pers comm.). It is likely that these models require a very long time series of age-length data to produce acceptable assessment outcomes and it is not recommended that catch sampling for kingfish is instigated specifically with age-length modelling in mind. However the length-age approach may be an option for kingfish after 10–15 years of length and age data has been collected; by which time more refined methodologies may be available.

7.5 YPR based methods

7.5.1 Setting catch levels based on an YPR derived estimate of F applied to an estimate of absolute biomass

Using YPR estimates in conjunction with an agreed set of biological reference points it is possible to determine appropriate fishing mortality rates (F). Harvest levels can therefore be derived given that the current stock biomass is known. Information needed to use this approach for kingfish are gear selectivity parameters and an estimate of stock biomass.

7.5.2 Per-recruit type B_{MSY} reference point proxies

The Ministry for Primary Industries (MPI) harvest strategy standard document (Ministry for Primary Industries 2011) provides guidelines on the use of B_{MSY} proxies; this document notes that x% B_0 and x% SSB/R reference points are not directly comparable except in situations where recruitment is independent of spawning stock biomass over the entire range of stock sizes. Based on the likely range of M (0.18 – 0.25) kingfish can be classed as a medium productivity species (Ministry for Primary Industries 2011) and as such, a target of 35% B_0 has been deemed by MPI as an appropriate B_{MSY} proxy which in turn equates an SSB/R of 40% ($F_{40\%}$).

The SSB/R analyses presented in this report suggest that $F_{40\%}$ (assuming the current recreational and commercial MLS) equates to a total mortality (Z) across kingfish older age classes in the order of 0.3. Estimates of Z can be derived using unbiased samples for the population “true” age composition through catch-curve analysis (Ricker 1975; Hilborn & Walters 1992; Haddon 2001).

Obtaining a truly unbiased representation of the underlying population age structure is problematic for most fisheries, as most fishing methods are prone to some level of selectivity bias (non-uniformity). Commercial trawl and setnet are clearly unsuitable for estimating Z in kingfish; as based on comparisons to recreational catches, both these methods poorly represent the older age classes. The broader range of age classes evident in samples collected from the eastern Bay of Plenty charter-boat fishery (McKenzie et al. 2014b) implies that sampling recreational kingfish fisheries for age in certain areas may be appropriate for estimating Z.

8 DISCUSSION

Biomass assessment techniques are likely to be impractical or simply not cost effective for kingfish; the net result being that yield estimation using direct biomass measures are not stock assessment options.

Surplus production and fully age structured models are suitable for kingfish stock assessment. Common to both modelling approaches are the requirements for a catch history and relative abundance indices (Table 4). Surplus production techniques require data covering a period of large biomass change in the stock. The most reliable catch and effort data series available to model kingfish stock productivity covers the period 1989–2004. Since the commercial fishery was largely constrained under non-targeting rules during this period (McKenzie et al. 2014a) there may be insufficient contrast in stock abundance to enable surplus production assessment.

Age/size based population modelling approaches have high information requirements (Table 4) the most critical being a time series of age/size obtained from at least one major method. In order to estimate selectivity some catch sampling is necessary from the other fishing methods. It is likely to be at least five years after a kingfish stock monitoring programme is instigated that an assessment could be undertaken.

Estimates of total mortality (Z) derived through catch curve analyses of recent age data collected from a uniform selectivity fishery (i.e. recreational line) can be used to assess the status of the fishery relative to $F_{40\%}$ SSB/R target. The $F_{40\%}$ approach is relatively cost effective when compared to other, more expensive approaches such as length and age population modelling, and is therefore currently the best stock assessment and monitoring option for kingfish given the moderate to low relative value and importance of the fisheries.

An understanding of stock boundaries is common across all kingfish assessment options (Table 4) making this a high kingfish research priority in the immediate future.

Table 4: Information requirements for SA approaches that have utility for kingfish management.

	Assessment approach			
Data requirements	**Surplus production**	**Age/length models**	**F40% SSB/R x Biomass**	**F40% SSB/R BMSY proxy**
selectivity by method		•	•	•
natural mortality		•	•	•
stock boundary	•	•	•	•
annual harvest by method	•	•		
abundance index	•	•		
growth estimates		•	•	•
age/size maturity		•	•	•
biomass estimate			•	
age/length sampling		•		•

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