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Manatū Ahu Matua

Forecasting quantity of displaced fishing.

Part 1: Challenger scallop fishery

New Zealand Aquatic Environment and Biodiversity Report No. 140.

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MPI is developing analysis tools for efficient and informative assessment of spatial fisheries management measures. Informative summary metrics, and computer tools that produce and display them, are useful for increasing the knowledge that goes into decision making. They supplement but do not replace the need for assessment of all relevant matters required by the governing statutes of the decision process.

An estimate of the average amount of fishing occurring in any particular area of interest is useful in a variety of fisheries management contexts. Where spatial regulations are being considered, such an estimate serves as a measure of potential fishing displacement. Here we define a useful measure of fishing displacement designed to be fit for assessments of undue adverse effects of marine farming on fishing (UAE test) and that also has wider application. A series of protocols for producing the defined metric are being developed for fisheries where suitable data is available.

While quantifying the amount of displaced fishing is not alone sufficient to fully assess the effects of displacement, it is a useful metric on its own for UAE tests as we explain. An on-going programme of work seeks to quantify additional matters in assessing the effects of displacement such as modelling fishing choices and outcomes for displaced effort.

In Part 1, we present a protocol for estimating the amount of commercial scallop fishing displacement likely to result from a spatial restriction in the SCA 7 scallop fishery. In this specific case, displaced catch is considered to be lost from the fishery so our measure of displacement satisfies an assessment of the effects of displacement.

We define the spatial extent of the SCA 7 fishery and use pre-season scallop biomass surveys to predict the distribution of scallop fishing. Comparisons are made of models for estimating catch from spatial cells based on the biomass of scallops in the cells and reported catch by sector. Additionally, we assess analysis options for estimating displaced catch and sensitivity to key parameters. All quantifiable sources of variance are combined with bootstrap resampling to give confidence intervals for a point estimate.

We demonstrate implementation of the analysis protocol with an assessment of the cumulative catch loss from the SCA 7 fishery from all previously authorised marine farms and preliminary estimates for the effect of the Tasman interim Aquaculture Management Areas (Tasman IAMAs). The parameters for these assessments are provided and explained. They may however change, as a result of consultation with affected parties.

The cumulative effect of marine farming to date is up to about 6.1% of the fishery. We can be 95% certain that the effect lies between 4.5 and 8.2%. Of that about 4.5% must be taken into account when assessing the Tasman IAMAs due to the transitional legislative provisions governing that particular case. These estimates are sensitive to the amount of area deemed to be excluded from scallop dredging with differences between analysts giving mean estimates of 6.1 and 5.7% (6.5% variation) in the case of the cumulative effects to date. Additionally 1.9% of the 6.1% estimated cumulative effect comes from the large seasonal spat catching consents for which the effect on fishing is disputed by marine farmers.

The preliminary indication of the effect of the Tasman IAMAs ranges from 0.7 to 2.4% depending on which catch history period is used to represent the spatial pattern of fishing in the future. On top of the existing cumulative effect (including the seasonal sites) this gives a catch loss of between zero and 1.6% that may have to be settled by agreement between the parties.

1 INTRODUCTION

We present here an analysis protocol to estimate the amount of commercial scallop fishing that would be displaced from any given area of the Challenger scallop fishery (SCA 7) should that area be removed from the fishery. This is part of a wider piece of work developing protocols to estimate the amount of commercial fishing of any fishstock displaced from any given area of the EEZ. Therefore, we start with a discussion of the general purpose of the wider project and present the design of measures desired to meet the purpose. We then explain why the SCA 7 fishery differs from other fisheries.

The main intent of this work is to make existing data readily available to support efficient and effective advice to decision makers. The statutory requirement to assess the effects of marine farming on fishing (UAE test) within 20 working days was a key motivation. Informative summary metrics, and computer tools that produce and display them, are useful for increasing the knowledge that goes into decision making. They supplement but do not replace the need for assessment of all relevant matters required by the governing statutes of the decision process.

1.1 The nature of assessments required for spatial allocation decisions

Marine spatial allocation decisions for different purposes, such as marine reserves, mataitai reserves or marine farms, are made under different sections of the Fisheries Act 1996[1] (the Act) or other legislation such as the Marine Reserves Act 1971. The nature of the required decision and supporting assessment varies depending on what is stated in the governing statutes. However, in most cases an estimate of the average amount of fishing occurring in the area of interest is likely to be useful either as an estimate of potential fishing displacement, if that is what is required, or as an independent source of information with which to benchmark submissions from stakeholders.

As an example, MPI's role in the allocation of space for marine farming requires the making of aquaculture decisions under section 186E of the Act. Aquaculture decisions require an assessment of the effects on fishing of new marine farming consents issued by territorial authorities under the Resource Management Act 1991 (RMA). The consent issued under the RMA does not take effect until MPI determines that the consent will not have an undue adverse effect on fishing (hence they are called UAE tests).

The matters to be assessed in making an aquaculture decision are specified in some detail in the Act and broadly require MPI to consider:

- the best available information on where fishing is carried out in the vicinity,
- the proportion of any fishery likely to become affected by the proposed aquaculture,
- matters that relate to the costs and opportunities for displaced fishing to shift elsewhere, and
- the cumulative effect on fishing of previous aquaculture decisions.

All aquaculture decisions are based on an assessment of two broad types of information. Firstly, information on the nature and quantity of fishing in the general locality, and secondly, information on the nature of the specific consent site that might be made available by the applicant or in submissions from affected parties. General information on past patterns of fishing can be analysed to some extent in advance to enable more efficient and effective analysis.

In the case of analysis of the effects on commercial fishing, the majority of aquaculture decisions involve small areas and are not contentious, but these small effects contribute to an ever increasing

[1] Or the Aquaculture Reform (Repeals and Transitional Provisions) Act 2004 which applies in some older and as yet unresolved cases. The difference between Acts governing MPIs role in aquaculture consenting are not material to the methodology developed here.

cumulative effect. For small, non-contentious applications, an analyst may need little more than an informative metric for the incremental and cumulative effect on commercial fishing. In other cases, quantitative metrics may be given lesser weight if supplementary information is available for assessment or if judgement of contradictory evidence is required.

To assist in efficient and timely UAE tests, MPI is developing assessment tools to:
1. summarise and map information on where commercial fishing is carried out;
2. estimate the proportion of any commercial fishery likely to be displaced through loss of fishing access to an area;
3. assess the options for displaced fishing effort and a range of possible likely outcomes for catches and costs of fishing; and
4. estimate the cumulative proportion of commercial fishing affected by aquaculture decisions to date.

The first three of these resources are likely to have general usefulness in a range of spatial assessments and the fourth is a specific assessment criterion for aquaculture decisions. The general analysis tool described here includes methods for tasks 1 and 2 as stated above and has already been used for UAE tests[2] and estimating the costs of spatial regulations for the protection of Maui's dolphin[3]. Task 3 is the subject of a longer term work programme.

The measure of displaced fishing described here is designed to be additive in order to estimate cumulative displaced fishing, a step towards task 4 above, but without yet accounting for the relocation of displaced fishing effort and its effects, understanding of which is required to give a measure of net cumulative effect.

The effects on recreational and customary fishing must also be assessed in aquaculture and other spatial allocation decisions but the assessment tool described here only relates to commercial fishing.

1.2 Defining a Quantitative measure of fishing displacement

In developing assessment tools to support spatial allocation decisions, it is important to clearly define the meaning of the quantities being produced so that they can be used and interpreted appropriately and any limitations in use or interpretation is understood by analysts and decision makers.

Here we define a single quantity to be produced as a measure of displaced fishing that is designed primarily to be useful for UAE tests on commercial fishstocks but as already stated has wider application.

1.2.1 Catch as a useful measure of fishing

An aquaculture decision requires an assessment of the effects of a marine farm consent on fishing. In the Act, a reservation for effects on commercial fishing requires the unduly affected fishstocks to be specified. The amount of fishing activity spent in each fishstock fishery may include fishing by

[2] Decision papers available for download from http://www.fish.govt.nz/en-nz/Commercial/Aquaculture/Marine-based+Aquaculture/Undue+Adverse+Effects+test/Current+Coastal+Permit+Applications+and+Recent+Aquaculture+Decisions.htm?WBCMODE=PresentationUnpublished%23MainContentAnchor

[3] section 12 of the Maui's Dolphin Threat Management Plan Consultation Paper: Sections 10 to 13 Maui's Dolphin Threat Management Plan Consultation Paper (pdf 2 MB) downloaded from here: http://www.fish.govt.nz/en-nz/Consultations/Hector+and+Mauis+Dolphins+Threat+Management+Plan/default.htm?wbc_purpose=Basic&WBCMODE=PresentationU on 22 October 2013.

various different fishing methods and both target fishing on that fishstock or fishing where the fishstock is an incidental bycatch. A useful summary measure of fishing needs to combine the effort from different fishing methods and account for the relative importance of the fishing to the total fishing on the fishstock.

The option developed here is to use catch as a measure of fishing. Catch is a comparable measure for fishing using different methods and strategies and is directly relevant for fishstocks. Furthermore, catch statistics are likely to be more accurate than fishing effort statistics.

Catch and the amount of time or effort spent fishing are not equivalent measures as they are unlikely to have a fixed proportional relationship across space. It is generally expected that fishing will occur where catch per unit of fishing effort (CPUE) is highest although this is an oversimplification. There is likely to be more fishing close to port than would be expected simply based on the distribution of biomass, because the economic return will be higher . Therefore, using catch as a measure of the amount of fishing is an approximation that may underestimate the amount of fishing lose to port.

1.2.2 Percentage catch displacement as a measure of relative effect on a fishery

The Act requires MPI to consider whether the adverse effect of a marine farming proposal on commercial fishing is undue. Accordingly, the assessment involves a comparison between the amount of fishing affected and the amount in the whole fishery. Furthermore, section 186GB(1)(b) requires the assessment to include the *proportion* of any fishery likely to become affected, and the Fisheries (Aquaculture Compensation Methodology) Regulations 2012 (the 2012 regulations) require MPI to estimate the *percentage* of the average annual catch loss of the fish stock above the threshold (taking into account any increased fishing costs).

For these reasons fishing displacement is measured as the percentage of average annual catch of a fishstock which will be lost or have to be caught elsewhere if access to the area for fishing is lost. Each loss is added to a running total of cumulative effects to address matter 186GB(1)(f) of the Act.

It is important to reiterate here that a measure of displaced fishing is only part of a measure of the effects of displacement on fishing. Ultimately we want to estimate the outcome of displaced fishing in order to understand the effect of displacement. A useful measure would be projected catch loss calculated as the difference between estimates of before and after catches in a fishery. It is anticipated in the 2012 regulations that MPI will in some way estimate average annual catch loss for fishstocks subject to aquaculture reservations (i.e. fisheries unduly affected by an aquaculture consent).

When projecting the outcome of displaced fishing, the worst case may be where none of the fishing effort displaced from a footprint can be redeployed by fishing elsewhere in that fishery and therefore all the associated catch is lost from the fishery. Any redeployment of effort elsewhere may be expected to reduce the catch loss even when accounting for downstream or domino effects on fishing at the location of redeployment.

For most fishstocks it is likely that displaced fishing effort will be redeployed but that there will be a cost in doing so and the net effect will be something less than total loss of the displaced catch. This suggests that an estimate of displaced catch can be used to indicate the maximum likely loss of catch and that until the cumulative displaced catch reaches the undue threshold we can assume that the true cumulative catch loss will be less than the threshold. Therefore, cumulative displaced catch is a useful measure for MPI to monitor and refer to in UAE tests. Whether total loss of displaced catch is in fact the worst case scenario or whether a domino effect could actually produce an even worse overall effect on fishing may need to be tested in consultation with affected parties.

1.3 Developing the required analysis tools

The measure defined above can be estimated for all space in every fishery with more or less uncertainty depending on the quality of the data used to spatially map the catch. In the worst case, catch of a fishstock can only be mapped to large Statistical Areas refined with knowledge of habitat distribution. In many fisheries, catch and effort is reported by coordinates of the location of fishing instead of by Statistical Area and these data allow finer resolution mapping. In some spatially confined fisheries regular biomass surveys may also be used in mapping.

We present the EEZ displaced fishing methodology project in two parts.

1. SCA7 fishery – using annual biomass surveys and reported catch statistics.
2. General Fisheries – using reported catch and effort statistics.

Modifications may be developed over time to improve estimates for other specific fisheries.

This report presents a protocol for quantifying displaced fishing in the specific case of UAE tests on the Challenger scallop fishery (SCA 7). Unlike other fisheries, the location of commercial SCA 7 fishing can be modelled using a combination of log book returns of catch and effort and annual pre-season abundance surveys. A separate report will be available soon that describes a procedure for estimating displaced fishing in fisheries where only log book returns of catch and effort are available for mapping the location of fishing.

1.4 The Challenger Scallop fishery

The SCA 7 fishery is the first fishery in which the cumulative effects of marine farming have approached a threshold for what is considered to be an undue adverse effect on the fishery, in this case decided as a loss of 5% of the annual average catch. This means that future marine farming consents in SCA 7 areas may lead to MPI making a “reservation” in relation to commercial fishing of the SCA 7 stock, whereby the marine farm cannot proceed without an aquaculture agreement between the applicant and the quota holders or a compensation agreement lodged following an arbitration process. Accordingly, MPI requires a precise estimate of the cumulative effects of all past aquaculture decisions and the incremental effect of each new marine farm proposals in order to specifically identify which whole or part of a proposal first reaches the threshold and how much catch might be lost above the threshold as a percentage of the average annual catch for SCA7. These estimates will guide the MPI decision maker and may also inform arbitration of fair compensation where required.

A previous protocol, dubbed the “scallop model” was presented for peer review to MPI’s shellfish science working group in 2006 (Ministry of Fisheries (2006). It was subsequently modified to adopt some but not all of the peer review suggestions, and used in subsequent aquaculture decisions. It received further review during court proceedings terminating in April 2013. This report revises the original protocol to address:

- outstanding matters from the 2006 peer review,
- matters raised in subsequent peer reviews,
- legal points decided by the High Court and Court of Appeal,
- matters subsequently identified during implementation.

These matters are summarised in Appendix 1.

Further to the discussion above on the design of an appropriate measure for displaced fishing, we need to consider the fact that SCA 7 is an enhanced fishery. Enhancement activities in an area, whether recent or not, might fall within a definition of fishing. An alternative possible measure of the amount of use of an area for scallop fishing might be the average level of success of past enhancement if such data were to exist. However, by definition, successful enhancement is always followed by fishing of the enhanced beds so successful investment in enhancement is factored into our measure of fishing based on catch. There remains a question of whether enhancement activity to rebuild stocks, even when not successful, maintains a continuity of use of space that should be taken into account. However, information on reseeding activities since 2007 is not readily available to MPI so has not been included in consideration of the design of this protocol. That is not to say it is not a matter that must be included in the UAE test, only that it is not included in our quantitative measure of displaced fishing.

A further matter relevant to the discussion in preceding sections but specific to the SCA 7 fishery pertains to the effect of displacement and whether displaced catch can be made up elsewhere. In the general case it is assumed that some, if not all, displaced catch will be made up from fishing elsewhere and the net effect will be something less than the total loss of displaced catch. To estimate net catch lost and costs of displacement in general, MPI needs an understanding of the options for deployment of displaced fishing effort. In the SCA 7 fishery, the species is sedentary, relatively short lived, and the fishery is generally not limited by the annual catch limit. For these reasons here we assume that all fishing opportunities are fully exploited and catch lost from a footprint will not be recoverable elsewhere i.e. the catch lost from a footprint is permanently lost from the fishery. No attempt is made to estimate the costs of trying to make up the displaced scallop catch elsewhere from the fishery. For the SCA 7 fishery only, the terms "catch displaced" and "catch loss" are considered to be equivalent, and are treated as such in the remaining sections.

1.5 Implementation Issues

This report delivers two products:

1. A methodology for estimating displaced catch in the SCA 7 fishery in a manner that is suitable for UAE tests.
2. An assessment of the cumulative effect to date of all existing marine farms on the SCA 7 fishery.

In this report we present and justify the analysis protocol and demonstrate sensitivity of outputs to parameter choices. We demonstrate its implementation with realistic examples of assessment of effects on the SCA 7 fishery. First, by estimating the cumulative effects of all past aquaculture decisions and second a preliminary assessment of the next marine farming proposal due for a decision, the proposed Tasman Interim Aquaculture Management Areas (Tasman IAMAs)[4].

However, the results presented here are not the authoritative implementation of the methodology in these example cases. Submissions from affected parties are to be taken into account in finalising the parameters used in the UAE test of the Tasman IAMAs including the cumulative effect to date. The definitive version of the cumulative effects of all existing marine farms decisions up to 20 January 2006 on SCA 7 will be published in a decision paper on the proposed Tasman IAMAs available by request from the Manager, Spatial Allocations, Fisheries Management, Ministry for Primary Industries or download from http://www.fish.govt.nz/Commercial/Aquaculture/Marine-based Aquaculture/Undue Adverse Effects test/Current Coastal Permit Applications and Recent Aquaculture Decisions .

[4] Assessment of this application is governed by the Aquaculture Reform (Repeals and Transitional Provisions) Act 2004 not section 186E of the Fisheries Act as stated in section 1.1 which applies to more recent marine farming applications. The difference is not material to the methodology developed here.

2 METHODS

2.1 overview of Analysis Protocol

We want to estimate the percentage of SCA 7 likely to be lost by removal of some space from the fishery. This analysis task has two parts. First we need to estimate the spatial distribution of annual catch. Then, we need to estimate the average annual proportion of catch likely to be lost by restricting fishing from an area (here termed a footprint). In the case of marine farming effects, we also want to know the cumulative amount of fishing displaced from all marine farm footprints.

The first part is a statistical undertaking to design the best estimator of catch in an area of interest and the second part relates to defining a suitable summary measure of incremental and cumulative relative catch loss.

Daily catch statistics are reported by Statistical Area (here termed sectors). Scallop biomass is routinely estimated at a finer spatial scale in scallop biomass surveys conducted prior to the beginning of each annual fishing season. We wish to model the fine scale distribution of catch by assuming that the spatial distribution of catch within sectors is related to the distribution of scallop biomass.

The size and shape of survey strata vary between annual surveys so for convenience we post-stratify surveys to a regular grid of cells within sectors and estimate the cell biomass each year from meatweight density estimates of cells apportioned from the intersecting annual survey strata.

Annual catch reported from each sector is apportioned to the same cells by a modelled relationship to biomass for each year where pre-season biomass was surveyed. The percentage of catch in the fishery coming from each cell can then be averaged over the years of available data to give the mean annual percentage of the fishery caught in that cell.

The proportion of a cell lost to fishing can then be multiplied by the percentage of the fishery caught in that cell and summed over all cells to give the required estimate of catch lost from a footprint, which in turn is summed over all footprints to give the cumulative effect. This procedure is illustrated in Figure 1.

2.2 Available data

Four parameters are required for the protocol shown in Figure 1: the mean meatweight density in each cell c and in each year y (M_{cy}), the area available for fishing in each cell, sector s and year (A_{csy}^{avail}), the scallop catch in each sector and year (C_{sy}) and the area of each cell lying within the footprint of interest f (A_{cf}). The data for these parameters come from the following sources.

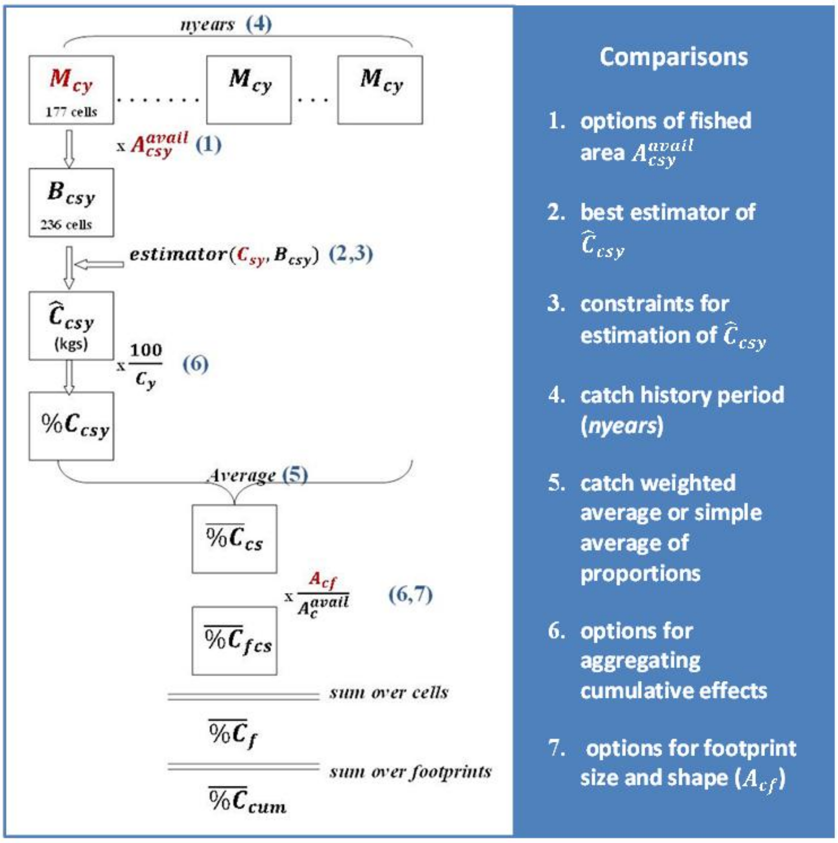

Figure 1: Diagrammatic view of analysis protocol for estimating the percent catch loss in a fishery from a footprint f, $\overline{\%C_f}$ and cumulative loss from all footprints, $\overline{\%C_{cum}}$. Five input parameters, shown in red, are M_{cy} the mean meatweight density of scallops (kgm^{-2}); A_{csy}^{avail} the area available for fishing in each cell c, sector s and year y; *nyears*, the catch history period; C_{sy}, reported catch by sector and year; and A_{cf}, the area of the footprint in the cell. The comparisons made to choose options for the final protocol are summarised on the right and referenced by number on the left. A key step is estimating catch from cells, $\hat{C}_{csy}$ using mean biomass from cells B_{csy} and the relationship between reported catch and biomass in sectors.

2.2.1 Reported catch by sector

Catch and effort in the SCA 7 fishery are reported daily by the statistical sectors shown in Figure 2. The annual scallop catch by sector and year (the parameter C_{sy} shown in Figure 1) is given in Table 1. The distribution of scallop fishing effort within sectors is known to be patchy and is assumed to generally reflect the underlying patchy distribution of the scallop beds themselves. Mapping the likely distribution of catch within sectors is possible using information on the distribution of scallops and assuming that the distribution of catch is related.

2.2.2 Annual pre-season dredge surveys

The SCA 7 fishery has been surveyed every year from 1994 to 2012 to estimate pre-season biomass available for fishing (Williams & Bian, 2012). Surveys are two-phase stratified random dredge surveys designed to estimate biomass in each of the main sectors of the fishery generally to a target precision of 10–20% CV. They are not specifically designed to

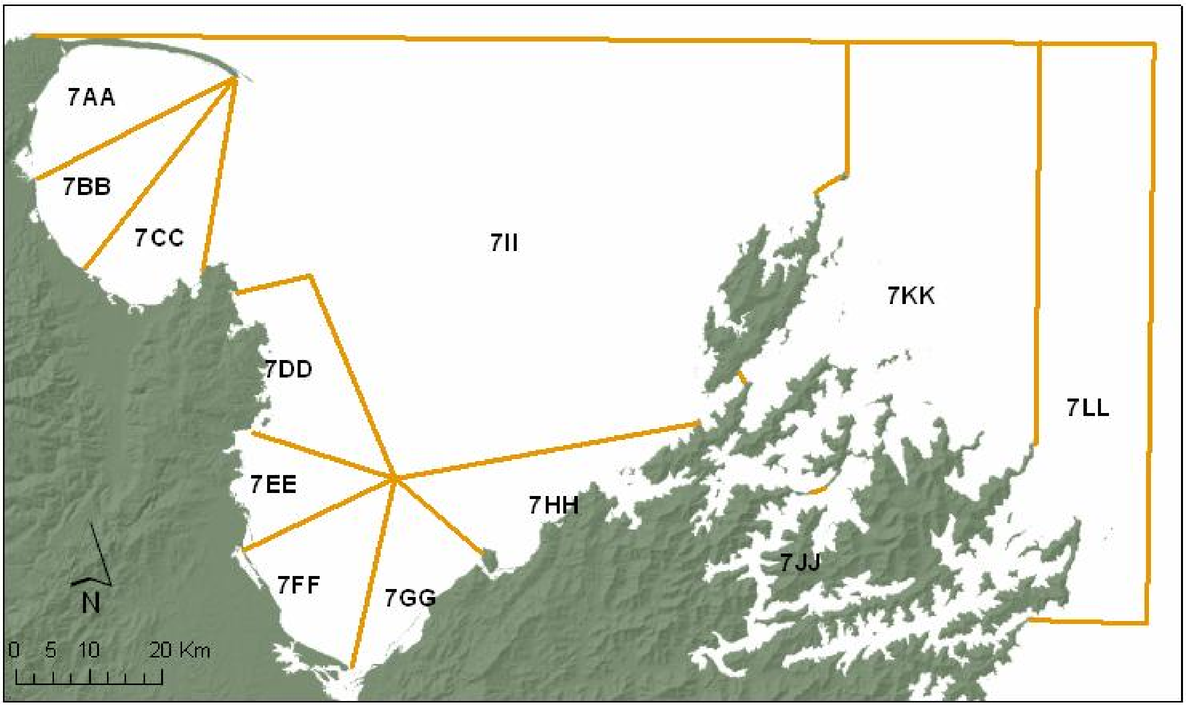

Figure 2: SCA7 sectors for reporting daily catch and effort.

Table 1: Annual landings of scallops in tonnes of meat weight by sector. Figures are groomed landings supplied by James Williams of NIWA.

Fyear	7AA	7BB	7CC	7DD	7EE	7FF	7GH	7II	7JJ	7KK	7LL
1996	111	12		11	0	36				60	
1997		40	1		2					58	
1998	94	187			17		61	71		117	
1999		92	421	28	88	26	13	1		7	
2000	39	163	91	5	13			10		16	
2001	50	559	44			6	25	7		25	
2002	100	218	45			4	34	7		62	
2003	28					96	11			52	18
2004	4	16			17	26	3			51	
2005	10	24	1			4	1			94	22
2006	13	13							1	41	
2007			128								6
2008		75								28	
2009	2	13	4							97	4
2010		10						1		57	17
2011			1							30	30
2012										25	21

estimate the distribution of scallops within sectors. However, survey strata are smaller than the fishery sectors and provide better spatial resolution of scallop distribution. However the precision of estimated mean density in each strata is less than the target for whole sectors and in some cases may be very low with CVs typically ranging from 20–100%. Imprecision in annual strata density estimates may be partly overcome by taking the mean over a number of years.

The annual biomass surveys provide estimates of recruited scallop density by tow (no. Scallops m^{-2}) and mean density by survey stratum. The greenweight density per tow (kgm^{-2}) was estimated in different ways between surveys. Early surveys weighed the catch from each tow (Osborne, 1998, Breen & Kendrick, 2000). Later surveys used a length weight relationship to estimate greenweight in each tow.

Mean scallop meatweight density estimates by survey strata for 1996 to 2005 used in the original scallop model (Ministry of Fisheries (2006) were derived from the greenweight density estimates at the time of the surveys, available meatweight conversion formulae and the most up to date dredge efficiency estimates as detailed in Kim & Breen (2005).

Since then, NIWA fisheries scientists have changed the procedure for conducting scallop surveys and reanalysed all the previous surveys with a standardised protocol. The new procedure uses bootstrapping to combine the variation from length-weight relationship, greenweight to meatweight conversion, dredge efficiency and variation of sample densities within strata as described in Williams & Bian (2012).

Strata areas and total coverage have varied between surveys. In order to give a common spatial reference for mean scallop density estimates between years, Challenger Scallop Enhancement Company (CSEC) re-stratified surveys up to 2005 to a common set of grid cells (Kim & Breen, 2005). The cells were 0.04 degree resolution over Tasman and Golden Bays and generally larger and defined by embayments in the Marlborough Sounds. The post-stratification procedure derived $\bar{M}_{cy}$, the mean meatweight density for each grid cell c and year y, from the weighted average of densities in survey strata intersecting each cell.

$$\bar{M}_{cy} = \frac{\sum_{t=1}^{nstrata} [\bar{M}_{yt} * A_{cyt}]}{\sum_{t=1}^{nstrata} [A_{cyt}]} \tag{1}$$

where the number of survey strata intersecting a cell is given by t={1,2,...,$nstrata$}, and $\bar{M}_{yt}$ is the mean meatweight density (kgm^{-2}) in strata t in survey year y; and A_{cyt} is the area (m^2) of survey strata t in grid cell c in year y.

The weighted average of strata means was used rather than going back to the original tow station data as the probability of sampling each station in a cell is different between neighbouring strata so tows within cells cannot be considered to be random samples and so they cannot be averaged to give an unbiased estimation (Kim & Breen, 2005).

Here we start with the 1000 bootstrap samples of mean strata meatweight density for each annual survey from 1997 to 2012 provided by Richard Bian of NIWA and post-stratify the surveys to cells using equation (1) from Kim & Breen (2005). The result is 1000 bootstrap estimates of mean meatweight density for each cell and year (the parameter M_{cy} shown in Figure 1).

2.2.3 The geographic boundaries of area available for fishing

In the protocol, the area defined as being used for commercial scallop fishing in each cell (A_{csy}) is used in the calculation of available biomass from mean density, and in the calculation of the area of a marine farm footprint (see next section). The biomass estimated to be available for fishing is calculated for each cell as the area of the cell multiplied by mean density of scallops in the cell.

The extent of commercial scallop fishing grounds have not been measured directly but were inferred from the known distribution of scallops and from consultation with fishers. The Ministry consulted fishers for this purpose in the early days of developing the procedure revised here (during the period 2004–06). An agreed map of the areas historically used for scallop fishing is shown in Figure 3.

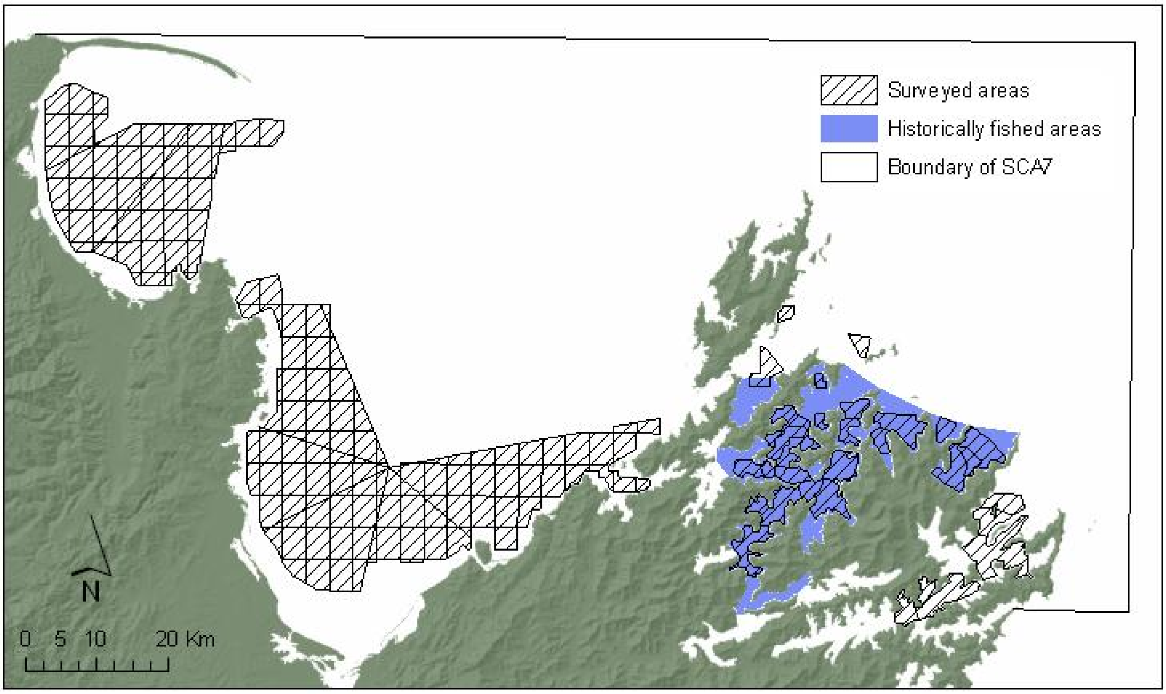

Figure 3: The defined extent of SCA 7 and areas historically fished and surveyed (hatched) and historically fished but not surveyed (shaded).

In Tasman and Golden Bays, the grid cells originally defined by CSEC, the scallop fishing company, cover the known extent of commercial scallop fishing grounds and most of the areas included within annual surveys. In the Marlborough Sounds, the area of historical fishing described by fishers was considerably more than the areas included in scallop surveys from 1996 onwards. This partly reflects area lost to the fishery from marine farm development prior to 1996.

After 2005, new areas in Queen Charlotte Sound were surveyed and fished and we have adjusted or added cells as required to cover all area surveyed. Figure 4 shows adjustments to the CSEC cells used in this protocol and the coverage of each cell by survey tows. The entire fishery was mapped to 177 cells. Cells that straddled sector boundaries were split so that cells belonged to only one sector and this gave a total of 236 cells in the fishery.

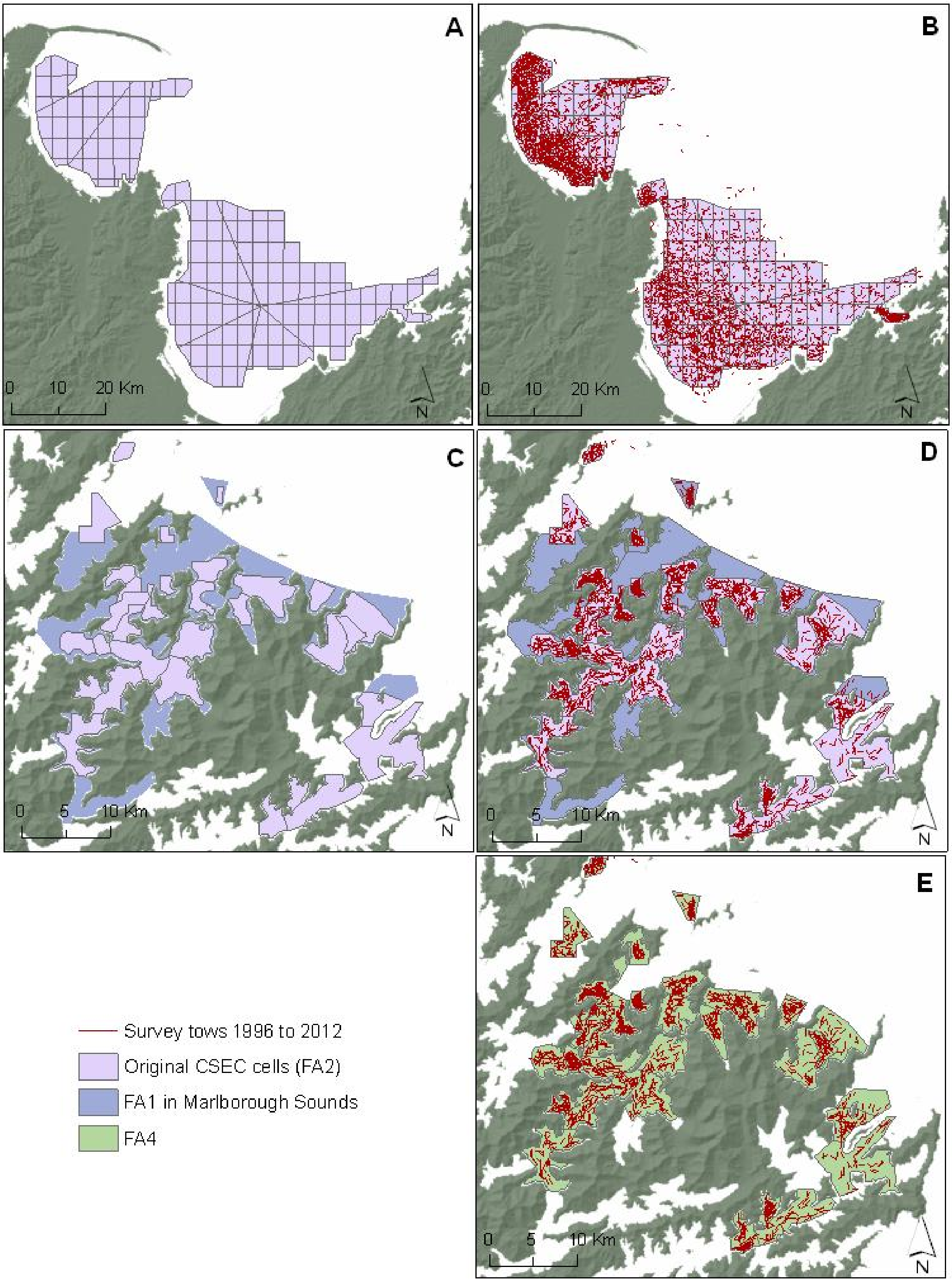

Figure 4: Set of cells used for annually estimating fishing intensity from scallop abundance surveys and catch landing statistics in Tasman and Golden Bays (A and B) and Marlborough Sounds (C–E). Distribution of survey tows (right). Dark shaded area in C is FA1, light shaded area is FA2. The distribution of tows shown in D does not adequately sample FA1. The alternative boundaries of the fished area FA4 is shown in E.

Mean density of scallops in a cell was estimated for each year where a survey stratum overlapped with a cell. All the Tasman and Golden Bay cells contain more than one tow over the time series giving confidence that variance in mean densities can reasonably be estimated. However, the coverage of survey tows in some of the large cells in the Marlborough Sounds is limited (Figure 4). The accuracy of mean density estimates for these cells cannot be determined.

While the use of these extended cells may be necessary for estimating the effect of the marine farming footprint up to 1996, their use beyond then is questionable. We confirmed with scallop fishers that survey strata cover the main known fishing grounds. We prefer to use cells based on the survey strata to avoid extrapolating sampling results to areas for which no sampling occurred, however, in doing so we risk underestimating the cumulative effect of historic marine farming decisions. As a compromise solution we suggest a set of polygons that extend the survey strata to include near shore areas close to surveyed areas where scallop fishing occurred prior to marine farming development.

Alternative estimates based on the three options for the spatial coverage of fishing grounds in the Marlborough Sounds described above were compared.

1. Fished area 1 (FA1) was the area used in the previous scallop model (Ministry of Fisheries, 2006) based on consultation with fishers but including area distant from biomass sampling effort.
2. Fished area 2 (FA2) was the maximum area covered by biomass survey strata over the years.
3. Fished area 4 (FA4) was the preferred compromise based on the survey strata extended to cover areas now occupied by marine farms but which it was considered could have been otherwise dredged but not extending as far away from surveyed areas as FA1.

The three options are shown in Figure 4. All three options for defining the extent of historically fished areas are subjective and the comparison serves to demonstrate the sensitivity of catch loss estimates to the parameter A_{csy}^{avail}.

Each time a marine farm is developed the area of the encompassing cell available for fishing reduces. So the cell areas used in the analysis protocol need to be regularly updated. Marine farm development may happen gradually over time and may happen at varying intervals after the commencement of the marine farm permit (i.e. licence, lease, marine farming permit or coastal consent). For practical reasons we assume that development happens within the same fishing year as commencement of the marine farm permit but after the end of the scallop fishing season.

Pre-season scallop biomass surveys are conducted in May–June each year and fishing mostly occurs in the season August to December. We have adopted the scallop fishing year April to March as the standard assessment year. So prior to each fishing season all the footprints of marine farming decisions made in the previous year up to the end of March must be aggregated and erased from the cells and A_{csy}^{avail} recalculated before it is used to estimate biomass available for fishing in the next season. However, if it was known that a permitted marine farm was not developed in any year and particularly if it was never going to be developed then it should not be included in the footprint.

For practical reasons the assessment of the cumulative effect of past marine farming decisions presented here is not based on annually updated cell areas. Instead we have divided the assessment period into time steps and updated cell areas at the end of each time step by subtracting the area removed from the fishery during the preceding period.

Assessments of cumulative effects were made separately for four periods:

1. Period1 - up to 30 September 1992 (P1)
2. Period 2 - 1 October 1992 to 31 March 1996 (P2)

3. Period 3 - 1 April 1996 to 20 January 2006 (P3)
4. Period 4 - 21 January 2006 to 31 March 2013 (P4)

From then on the A_{csy}^{avail} parameter will be updated annually in April each year.

A separate estimate was generated for the first time period because in the case of the UAE test on the Tasman IAMAs, the High Court decided that MPI's assessment of the cumulative effects of marine farming on the SCA 7 fishery should only consider effects of marine farming decisions made after 1 October 1992 when this fishery came into the Quota Management System. The 2011 aquaculture reform legislation clarified that all marine farms should be included in cumulative effects assessments for all other applications. In effect the Tasman IAMA assessment will be an exceptional case where the cumulative effects will exclude this first time period but all subsequent assessments will include it.

The Tasman IAMA application was dated 20 January 2006 and only marine farms decisions prior to that date need to be considered in the assessment of cumulative effects for that case so a separate estimate is produced here for the period of cumulative effects that specifically applies to the Tasman IAMA case.

The period from 1992 to 2006 was divided into the time before and after annual scallop survey data became available in order to consider the three options for the definition of grid cells in the Marlborough Sounds discussed above. Option FA2 based on scallop survey strata was only applied after 1996 when the strata were first designed.

The fourth assessment time period, 1 April 2006 to 31 March 2013, brings the cumulative assessment up to date for all future applications. Marine farm applications are generally assessed in chronological order of receipt but some marine farm decisions in the Marlborough Sounds have been made whilst the Tasman IAMA case has been stalled in court proceedings on the basis that they had no effect on the SCA7 fishery. The only matter in the Tasman IAMA assessment being contested in court was the effect on the SCA 7 fishery.

2.2.4 Footprint of current and proposed marine farm development

A footprint is defined as the area from which dredging for scallops is effectively excluded. Footprints are the area of overlap between the scallop fishery (as defined in Section 2.2.3) and the area from which a proposed spatial restriction will actually restrict scallop dredging.

The protocol described here starts with a given footprint polygon. The protocol does not account for uncertainty in the area of the footprint. Analysts are expected to make a judgement on the size and shape of the footprint and in cases where contradictory evidence exists the decision maker can be presented with estimates for different footprint options.

In the case of a marine farm with subsurface structures it is generally accepted that all fishing is excluded from the area containing structures. In the case of mobile fishing methods such as dredging the footprint might also include some area beyond the boundary of the farm for navigation and safety reasons.

The cumulative marine farming footprints presented here (one for each of the four time periods stated in the previous section) were created by buffering each marine farm with a radius of 50 m in the Marlborough Sounds or 75 m in the more open waters of Tasman and Golden Bays and merging the resulting polygons into one shape. These distances were based on extensive consultation MPI undertook with marine farmers, SCA 7 scallop fishers and independent experts such as the Harbourmaster during the period 2006 to 2011.

The merged polygons were expanded to include additional area beyond the buffer zones that was deemed to be blocked to access for dredging by the placement of farms. Examples are shown in Figure 5. The resulting polygons were clipped to the defined fishing grounds in order to calculate the area of overlap between the area blocked for dredging and fishing grounds i.e. the footprint, the area lost to the fishery. Footprints for previous time periods were erased from each new footprint so that new footprints were incremental to and non-overlapping with, footprints already assessed and included in the running total of cumulative effects.

We present here three options for the size and shape of the footprint of all existing marine farms.

1. Footprint 1 (FT1):- The footprint used in the original scallop model developed in consultation with commercial scallop fishers in 2004 to 2006 and more recently adjusted to take account of improved accuracy on the location of marine farms and split into the required time periods.
2. Footprint 2 (FT2): An alternative footprint based on more recent assessment of area likely to have been lost to commercial scallop dredging activity giving a smaller footprint that 1 above.
3. Seasonal Footprint: A footprint for the seasonal spat catching areas in Tasman and Golden Bays so that the disputed effect of these areas can be presented separately.

A comparison of 1 and 2 above gives an indication of the sensitivity of the output to the parameter A_{cf}, the area of each cell in the footprint.

2.2.5 GIS procedures

All fished cells, marine farms, and footprints are created as shapefiles in ArcGIS 10.0. The area of each shape is calculated with an inbuilt function using the New Zealand Transverse Mercator projection (NZTM 2000).

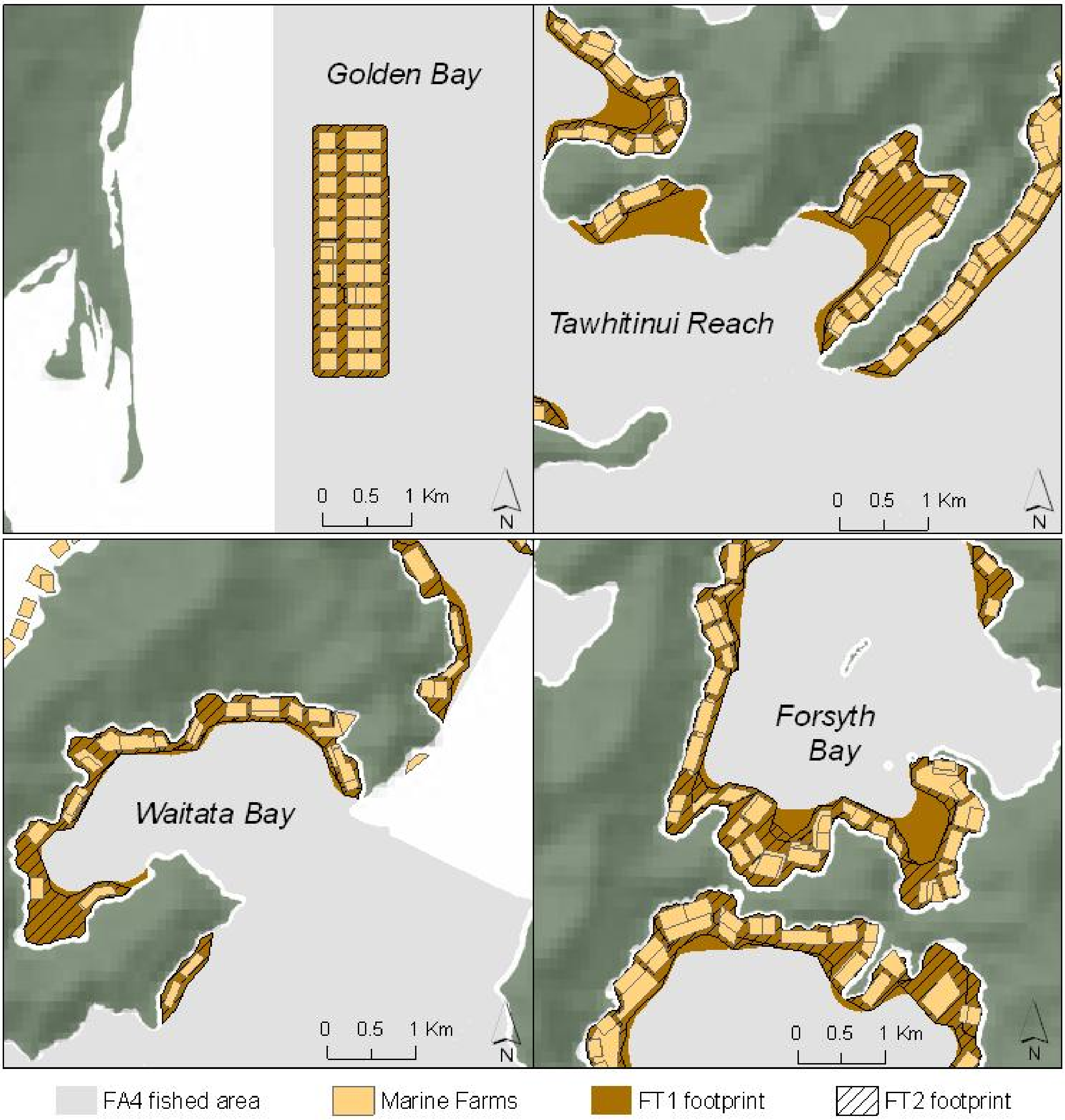

Figure 5: Examples of areas included in footprints for assessing the cumulative effects of existing farms. Only farms granted permits after 1 October 1992 were included in the cumulative footprints.

2.3 Best estimator of Cell catch

A range of models and explanatory datasets were tested for estimating the mean and 95% confidence interval of annual catch taken from cells. Two main sources of variance in estimating mean cell catch were identified for incorporation into the estimator – variance in the estimates of mean cell biomass (from the distribution of bootstrap estimates of cell biomass described in Section 2.2.2) and variance in the relationship between biomass and subsequent catch. To incorporate the latter we needed to first choose the best form of the catch:biomass relationship. We incorporate variance in the regression into our estimator of cell catch by sampling from the regression residuals in the calculation of each bootstrap estimate of cell catch to give a distribution of cell catch estimates. Therefore, it is important that the regression residuals be independent and identically distributed (iid).

Three main aspects of selecting the best estimator of cell catch were tested:

1. selection of model components to best describe the catch:biomass relationship,
2. selection of biomass data to fit,
3. constraints to apply.

In all cases the procedure is run on 1000 bootstrap samples for each cell and each year so we end up with 1000 estimates of $\hat{C}_{csy}$ for every 236 cells, for every year.

2.3.1 Choice of model form

To estimate $\hat{C}_{csy}$ we assume that

$$C_{csy} \propto B_{csy}, \tag{2}$$

Where, $\bar{B}_{csy} = (\bar{M}_{csy} * A_{csy})$, $\bar{M}_{csy}$ is density of scallops in meatweight per m^2, and A_{csy} is area of the cell *c*.

To explore the nature of the relationship between catch and biomass and to choose the best estimator we start by representing our estimator in the generic form

$$\hat{C}_{csy} = f(\beta g(\bar{B}_{csy}) + \alpha + \varepsilon_2) + \varepsilon_1$$

where, $\beta, \alpha, \varepsilon_2$, are unknown parameters for a modelled relationship between sector biomass, B_{sy}, and subsequent catch, C_{sy}. g is some function of $\bar{B}_{csy}$, and ε_1 accounts for random error in $\bar{B}_{csy}$.

Options to improve our estimator from (2) progressed through the set of models described next and summarised in Table 2. Models were compared using the AIC criterion:

A. *Fixed proportion* - where mean density per cell is used to estimate cell biomass and the relationship between catch and biomass in each year and sector is set at a fixed proportion.

$$\hat{C}_{csy} = \frac{\bar{B}_{csy} * C_{sy}}{\bar{B}_{sy}}, \qquad so\ \beta = \frac{C_{sy}}{\bar{B}_{sy}}\ and\ \alpha = \varepsilon_2 = \varepsilon_1 = 0$$

$$g(x) = x, f(x) = x$$

B. *Fixed proportion (bootstrapped)* – the same relationship as A above using bootstrap samples to give a measure of variance in mean cell catch estimates

Var(C_{csy})= $\sum_{b=1}^{n} \varepsilon_b^2$, where ε_b= $C_b - \bar{C}$

$$\hat{C}_{csy} = \frac{B_{csy} * C_{sy}}{B_{sy}} + \varepsilon_b, \qquad \text{so } \beta = \frac{C_{sy}}{\bar{B}_{sy}}\ and\ \alpha = \varepsilon_2 = 0, \quad \varepsilon_1 = \varepsilon_b$$

$$g(x) = x, f(x) = x$$

C. *Linear regression, predict from mean* ⁺ where cell catch is predicted from cell biomass based on a linear regression model fitted to all the paired annual observations of sector catch and sector biomass. Fitted cell catch values are constrained to sum to known sector catch.

$$\hat{C}_{csy} = \left[[\beta B_{csy} + \alpha] * \frac{C_{sy}}{\sum_{c=1}^{ncells} \hat{C}_{csy}} \right] + \varepsilon_b,$$

$$so\ \varepsilon_2 = 0, \varepsilon_1 = \varepsilon_b, \beta\ and\ \alpha\ are\ derived\ from$$

$$C_{sy} = \beta B_{sy} + \alpha + \varepsilon_i \qquad (3)$$

$$f(x) = x \frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})} \quad , g(x) = x$$

D. *Linear regression, predict with residuals* ⁺ the same as C above but predicted values are taken from the sample distribution of the regression rather than the mean by randomly drawing ε_2 from the $\varepsilon_i's$ in equation (3)

$$\hat{C}_{csy} = \left[[\beta B_{csy} + \alpha + \varepsilon_i] * \frac{C_{sy}}{\sum_{c=1}^{ncells} \hat{C}_{csy}} \right] + \varepsilon_b$$

$$where\ \beta, \alpha, \varepsilon_i\ are\ derived\ from\ equation\ (3)$$

E. *Sector-wise linear regression* ⁺ where separate regression parameters are derived for each sector

$$\hat{C}_{csy} = \left[[\beta_1 B_{csy} + \sum_{i=2}^{12}[\beta_i D_i] + \alpha + \varepsilon_2] * \frac{C_{sy}}{\sum_{c=1}^{ncells} \hat{C}_{csy}} \right] + \varepsilon_b$$

$$where\ D_i = 1\ if\ i = s\ else\ 0, and\ \beta i, \alpha, \varepsilon_2\ are\ derived\ from$$

$$C_{sy} = [\beta_1 B_{sy} + \sum_{i=2}^{12}[\beta_i D_i] + \alpha + \varepsilon_i] \qquad (4)$$

$$f(x) = \left(x + \sum_{i=2}^{12}(\beta_i D_i)\right) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right) \ , g(x) = x, \beta = \beta_1$$

F. *Log-linear regression*

Same as D but $f(x) = \log_e(x) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$ and $\beta, \alpha, and\ \varepsilon_2\ are\ derived\ from$

$$\text{Log}\ (C_{sy}) = \ \beta B_{sy} + \alpha + \ \varepsilon_i \tag{5}$$

G. *Log-log regression*

Same as F but *g(x)* = $\log_{e}\ (x), and\ \beta, \alpha, and\ \varepsilon_2\ are\ derived\ from$

$$\log\ (C_{sy}) = \ \beta \log\ (B_{sy}) + \alpha + \ \varepsilon_i \tag{6}$$

H. *Log-linear quadratic regression*

$$\hat{C}_{csy} = \ \left[\left[\beta_1 B_{csy} + \beta_2 B_{csy}^2 + \alpha + \ \varepsilon_2 \right] * \ \frac{C_{sy}}{\sum_{c=1}^{ncells} \hat{C}_{csy}} \right] + \varepsilon_b$$

where $\beta_1\ , \beta_2, \alpha, and\ \varepsilon_2\ are\ derived\ from$

$$\log\ (C_{sy}) = \ \beta_1 B_{sy} + \beta_2 B_{sy}^2 + \alpha + \ \varepsilon_i \tag{7}$$

$$f(x) = \left(x + \beta_2 B_{csy}^2 \right) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells} \hat{C}_{csy}} \right), \ g(x) = x, \ \ \beta = \beta_1$$

Table 2: Summary of the differences between tested models for estimating $\hat{C}_{csy}$. Models A to F, G1, G3 and H are comparisons of model forms all using the same sector biomass data explained in Section 2.3.1. Models G2, G3 and G4 give the comparisons of the sector biomass data set explained in Section 2.3.2

Model	$f(x)$ $x = \beta g(\bar{B}_{csy}) + \alpha + \varepsilon_2$	$g(x)$ $x = \bar{B}_{csy}$	β	α	ε_2	ε_1	B_{sy}
A	x	x	$\frac{C_{sy}}{\bar{B}_{sy}}$	0	0	0	$B^0_{sy} < \max(B^0_{csy})$
B	x	x	$\frac{C_{sy}}{\bar{B}_{sy}}$	0	0	ε_b	$B^0_{sy} < \max(B^0_{csy})$
C	$x\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}$	x	$\hat{\beta}$	$\hat{\alpha}$	0	ε_b	$B^0_{sy} < \max(B^0_{csy})$
D	$x\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}$	x	$\hat{\beta}$	$\hat{\alpha}$	ε_i	ε_b	$B^0_{sy} < \max(B^0_{csy})$
E	$\left(x + \sum_{i=2}^{12}(\beta_i D_i)\right) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$	x	β_1	$\hat{\alpha}$	ε_i	ε_b	$B^0_{sy} < \max(B^0_{csy})$
F	$\log_e(x) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$	x	$\hat{\beta}$	$\hat{\alpha}$	ε_i	ε_b	$B^0_{sy} < \max(B^0_{csy})$
G1	$\log_e(x) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$	$\log_e(x))$	$\hat{\beta}$	$\hat{\alpha}$	0	ε_b	$B^0_{sy} < \max(B^0_{csy})$
G2	$\log_e(x) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$	$\log_e(x))$	$\hat{\beta}$	$\hat{\alpha}$	ε_i	ε_b	all
G3	$\log_e(x) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$	$\log_e(x))$	$\hat{\beta}$	$\hat{\alpha}$	ε_i	ε_b	$B^0_{sy} < \max(B^0_{csy})$
G4	$\log_e(x) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}(\hat{C}_{csy})}\right)$	$\log_e(x))$	$\hat{\beta}$	$\hat{\alpha}$	ε_i	ε_b	$B^{07}_{sy} < \max(B^{07}_{csy})$
H	$(x + \beta_2 B^2_{csy}) \times \left(\frac{C_{sy}}{\sum_{c=1}^{ncells}\hat{C}_{csy}}\right)$	x	$\hat{\beta}_1$	$\hat{\alpha}$	ε_i	ε_b	$B^0_{sy} < \max(B^0_{csy})$

The simplest form of the relationship between catch and biomass in a cell is the assumption that catch is a fixed proportion of biomass in the cell (specific to year and sector). Using this model, catch in cells was evaluated with the mean cell biomass (Model A) or the sampling distribution of mean biomass (Model B). Model A is the approach taken in the original scallop model. The variance of mean cell catch in Model B only includes variance in the estimates of cell biomass. Another important source of variance is likely to be variation in catch as a proportion of available biomass in a cell. It is unlikely that all biomass detected in surveys is fished each year or that all biomass patches that fishers find throughout a season were detected in surveys.

We attempt to incorporate this source of variance into the measure of uncertainty in the point estimate of catch from a footprint by building a model of how catch varies with biomass from the observations available at the sector level. Model C allows the proportion of biomass taken as catch to vary in a constant manner with biomass by year and sector (applying a constant linear relationship between catch and biomass). Model D incorporates random variation in the relationship between catch and biomass by sampling from the residuals of the regression. Models E, F, G and H are attempts to improve the distribution of the residuals by applying separate regressions by sector (Model E), fitting biomass to $\log_e$ transformed catch (Model F), taking the $\log_e$ of both catch and biomass (Model G) and adding a quadratic term to the $\log_e$ linear form (Model H).

2.3.2 Choice of explanatory variable dataset

In addition to testing different structural forms of the relationship between sector biomass and subsequent catch we also tested variants of the explanatory variable dataset.

Kim & Breen (2005) tested a variety of different density parameters from annual pre-season dredge surveys for predicting seasonal catch in the SCA 7 fishery including density by numbers, greenweight, meat weight, and with five levels of commercial density threshold, taken at the time of the surveys and projected forward to the time of fishing. They concluded that biomass in terms of meatweight of recruited scallops above a residual density of 0.07 scallops m^{-2} at the time of the survey ($B^{0.07}$) was marginally the best predictor of subsequent catch in each sector. The rationale for using scallop density above a threshold to predict fishing catch is that fishing will only occur in areas where scallop density is sufficient to support economically viable catch rates.

The sector biomass dataset used here was produced using an analysis procedure revised from that used by Kim & Breen so the comparison between B^0 and $B^{0.07}$ as predictors of catch was repeated.

The predictive model of catch from biomass was required to predict cell catch from cell biomass but uses the observed relationship between sector biomass values and subsequent reported catch by sector. Sector biomass values generally ranged up to 1000 tonnes whereas cell biomass values ranged up to 500 tonnes. Therefore, the part of the regression that we want to fit best is where sector biomass lies within the range of cell biomasses. Larger sector biomass points might overly influence the least squares model fitted. Accordingly, we tested models based on the full sector biomass dataset against sector biomass values no larger than the maximum cell biomass values.

The three explanatory datasets compared were therefore:

1. B_{sy}^{0} - Model G2
2. $B_{sy}^{0} < \max(B_{csy}^{0})$ - Model G3
3. $B_{sy}^{0.07} < \max(B_{csy}^{0.07})$ - Model G4

These were tested in regression equation (6) above and are summarised in Table 2.

2.3.3 Sensitivity to constraints

In addition to comparing Models A to H and the effect of three different explanatory datasets for establishing the regression coefficients in Models C to H, we also tested the sensitivity of model outputs to two built-in constraints.

Models C to H as described above constrain the sum of cell catch within a sector to the observed catch for the sector. This is done by scaling up or down, under- or over-estimates of sector catch. An alternative option uses the uncorrected cell catch estimates. Applying the constraint maintains relative value between sectors whereas removing the constraint places more weight on the catch biomass relationship to identify potential areas of catch. In both cases the total annual estimated catch over all cells equates to 100% of the fishery in that year.

A second constraint decision relates to the handling of missing data. Cells that are not surveyed in any particular year can be assigned zero biomass and therefore zero catch or can be left empty in which case they are not included in subsequent averages. If cells are left empty then the sum of all averaged cells totals to more than 100%. If the sum of averages is constrained to equal 100% we are in effect assigning all reported catch to areas that were surveyed and no allowance is made for fishing in areas not surveyed.

Three options tested for the effect of constraints

1. Missing cell biomass data set to 0 biomass and $\hat{C}_{sy} = C_{sy}$
2. Missing cell biomass data left empty (set to "NA") and $\hat{C}_{sy} = C_{sy}$
3. Missing cell biomass data set to 0 biomass and $\hat{C}_{sy} \neq C_{sy}$

2.4 Summary measure of percent catch loss

With annual estimates of catch from each cell established we are left with finding a suitable method to use cell catch and footprint areas to estimate displaced fishing in a way that can be aggregated to a cumulative measure. Figure 1 diagrammatically shows the procedure of converting cell catch to percent of the fishery caught in each cell and averaging that over a period of years. The mean fishery percentage in each cell is multiplied by the proportion of each cell that occurs in a footprint and summed over the 236 cells to give the required estimate of the percentage of the fishery displaced by the footprint.

Variations in the procedure are examined at three of the steps just described.

1. Catch history period – how many years should be averaged i.e. what is the value of *nyears?*
2. Method for summarising annual cell estimates – is it better to use a simple average of percentage values or a catch weighted average?
3. Aggregating displaced catch – three variations for calculating incremental effects that sum to the cumulative effect are compared.

2.4.1 Catch history period

A choice needs to be made on the length of time period and which years to be used for estimation of $\overline{\%C_{cs}}$. Measuring the past average annual use of an area only needs information about the actual past use and a decision on how many years to include in the average. However, if the intention is to use such a measure as an estimate of likely fishing displacement if the status of an area was to change then we need to choose a past period to average that is representative of the likely future.

In estimating the long-run average pattern of scallop catch, the precision of the estimate will improve with the length of the data time-series supporting the estimate. However, if annual catch in some locations has changed or has a trend, a long term average may not give the most accurate estimate of future catch patterns. In the case of a fishery showing a trend, we want our measure of fishing to reflect the direction of the change. If fishing activity has been increasing then the measure should reflect likely increasing importance of the area to fishing in the future. Conversely, if the amount of fishing in an area is declining then so is the likely future importance of that area to the fishery. Compared to a short-term recent average, a long-term average will inflate the measure of fishing when fishing in an area is declining and discount the measure of fishing when fishing has been increasing.

The past spatial and temporal variation in scallop catches and densities were examined to determine the extent to which ecological or statistical evidence or knowledge can inform this choice. In essence we want to identify the catch history period that best represents likely future fishing patterns if possible. More information on the Challenger scallop fishery can be found in Williams et. al. (2013).

2.4.2 Summarising annual cell estimates

To account for interannual variability in the spatial distribution of scallop fishing the importance of each cell to the fishery is averaged over a period of years. This averaging also increases the amount of survey data upon which mean cell catch is based. There are two options for this summary statistic, either a simple average:

$$\overline{\%C}_{cs} = \sum_{y=1}^{nyears} \left[\frac{\hat{C}_{csy}*100}{C_{sy}}\right] / nyears$$

Or a catch weighted average:

$$\overline{\%C}_{cs} = \frac{\sum_{y=1}^{nyears}[\hat{C}_{csy}]}{\sum_{y=1}^{nyears}[C_{sy}]}*100$$

The sensitivity of the result to this choice is tested and the two options are compared.

2.4.3 Aggregating displaced catch

From this point, Figure 1 shows how estimating the percent catch lost from a footprint involves applying the proportion of area lost in a cell to the cell estimate of $\overline{\%C}_{cs}$ and summing all the resultant cell effects to give $\overline{\%C}_f$ our measure of the displaced catch from the footprint. However, if calculated as shown in Figure 1, cumulative effects will be overestimated because percentage effects are calculated on an ever decreasing fishery. A_{csy}^{avail} is reduced each year so the biomass available for fishing is calculated each year using an updated area available for fishing multiplied by the current years estimate of scallop density in each cell. Applying the protocol strictly as shown in Figure 1 to sequential reductions of available area by 25% of each starting cell area gives cumulative effects of 25, 58, 108 and 208% rather than the desired result of 25, 50, 75 and 100%.

We tested three methods of correcting this bias and producing additive measures of effect.

1. Baseline area method. Instead of taking the area of a footprint as a proportion of the current cell area available for fishing we could define the baseline area of each cell with which to calculate the proportion of the cell removed. So,

$$\overline{\%C}_{fcs} = \frac{\sum_{y=1}^{nyears}\left[\frac{\hat{C}_{csy}}{C_y}\right]}{nyears} * \frac{A_{cf}}{A_c^{baseline}}$$

2. Cumulative footprint method – instead of analysing a new footprint in isolation we could reanalyse the cumulative footprint each time a new estimate of effects is required and take the incremental effect to be the difference between the old and the new estimate of cumulative effect. So,

$$\overline{\%C}_{fcs} = \overline{\%C}_{cum}(new) - \overline{\%C}_{cum}(old)$$

where,

$$\overline{\%C}_{cum} = \frac{\sum_{y=1}^{nyears}\left[\frac{\hat{C}_{csy}}{C_y}\right]}{nyears} * \frac{A_{cf\,cum}}{A_c^{avail}}$$

3. Remaining fishery method – instead of estimating $\%C_{csy}$ as the percentage of the total fishery it can be the percentage of the remaining fishery after previous losses. So the original fishery would be set at 100% and the present day fishery would be 100% less the cumulative effect of footprints to date. So,

$$\overline{\%C}_{fcs} = \frac{\sum_{y=1}^{nyears}\left[\frac{\hat{C}_{csy} * 100 - \overline{\%C}_{cum}}{C_y}\right]}{nyears} * \frac{A_{cf}}{A_c^{avail}}$$

In the first instance, to test that each of these three options correctly sums cumulative effects we applied them to the simple case of sequential reductions of A_{csy}^{avail} by 25% of each starting cell area where the expected result is cumulative losses of 25, 50, 75 and 100% sequentially. It is expected that all three methods will perform correctly on this simple test but that they may give slightly different results for marine farming footprints because of the differences in timing of the application of the footprint in relation to the spatial and temporal patterns of scallop density in each cell.

The baseline area method and cumulative footprint method should be identical if the same catch history period is used for every footprint. If different catch history periods are chosen for assessing footprints the baseline area method will maintain the catch history option as applied at the time whereas the cumulative footprint method will apply the latest choice of catch history period to all the footprints.

Before choosing which option best fits the nature of the UAE test we examine the sensitivity of the output estimates to the choice of aggregation method using the first three cumulative marine farming footprints and the footprint for the TIAMA. The latter footprint is assessed with a different catch history period to the first three footprints.

2.4.4 Estimating uncertainty

In the results presented here the variance of $\overline{\%C}_{fcs}$ is estimated by bootstrapping. Williams & Bian (2012) produced bootstrap sample variance of $\overline{M}_{yt}^{0}$ for all survey years 1996 to 2012. Bootstrapping combines the sampling variance for the mean of tow densities, the regression of greenweight to length, the meat weight conversion factor and dredge efficiency estimates.

The entire procedure described here is performed on the 1000 bootstrap samples of $\overline{M}_{yt}^{0}$. Therefore, we get 1000 estimates of $\overline{\%C}_{fcs}$ for each cell, from which we get a mean and 95% confidence interval for the mean. Actual landings by sector and areas of strata, cells and footprints are assumed to be measured without error.

The estimate and quantified uncertainty should be accurate if calculated mean cell densities adequately represent the mean cell density in the footprint area of the cell. This is a necessary simplification. We have utilised the finest resolution information available on where fishing occurs and at that resolution have to assume that mean percentage catch from the cell has uniform distribution throughout the cell. This may not strictly hold for every small area within every cell or in fact any cell, but in the long run as the size of a cumulative footprint occupies more and more of a cell, the mean and variance of estimated catch loss from that cell will approach our estimate of $\overline{\%C}_{cs}$ with quantified uncertainty for the whole cell.

Clearly the accuracy of our estimate of catch lost from a footprint will be better for large footprints and therefore be better for the cumulative footprint than for any small incremental footprint.

In order to simplify future implementation of the analysis protocol all steps in the procedure have been pre-analysed and a new quantity calculated:

$$\overline{\%C}_{cs}(ha)^{-1} = \frac{\overline{\%C}_{cs}}{A_c^{avail}}$$

From the 1000 estimates of $\overline{\%C}_{cs}(ha)^{-1}$ we get a mean and 95% CI. The final step is then

$$E\left(\%C_f^{lost}\right) = \sum_{s=1}^{nsectors}\left[\sum_{c=1}^{ncells}\left[A_{cf}E\left(\overline{\%C}_{cs}(ha)^{-1}\right)\right]\right]$$

And variance is then given by

$$Var\left(\%C_f^{lost}\right) = \sum_{s=1}^{nsectors}\left[\sum_{c=1}^{ncells}\left[\sum_{s'=1}^{nsectors}\left[\sum_{c'=1}^{ncells}\left[COV\left(A_{cf}\overline{\%C}_{cs}(ha)^{-1}, A_{c'f}\overline{\%C}_{c's'}(ha)^{-1}\right)\right]\right]\right]\right]$$

3 RESULTS

3.1 Modelling Biomass and Catch at Sector Level

Reported annual catch by sector varies considerably and a significant proportion of the variance is explained by the pre-season biomass of scallops occurring in each sector ($F_{1,70} = 99.3$, $p<0.001$). Catch from cells is expected to be related to cell biomass in a similar manner to that for sector catch and biomass although variance in the relationship for cells is likely to be higher.

Historically, biomass above a minimum density threshold (usually 0.07 scallops m^{-2}) has been used to predict likely catch levels for the season ahead. Paired observations of estimated sector biomass and subsequent reported catch are shown in Figure 6 for the two datasets - biomass above 0.07 scallops m^{-2} (B^{07}) and all recruited biomass (B^0 i.e. biomass above zero density threshold). For both datasets, the relationship is variable but significantly positive ($t > 8.5$, $p<0.001$).

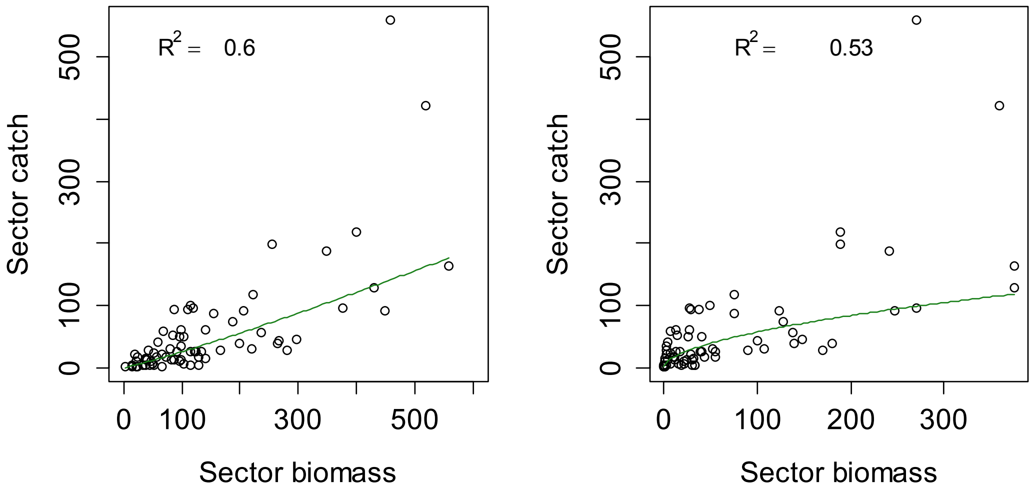

Figure 6: Reported catch by estimated biomass for all sectors and years combined using two different explanatory datasets, B^0 (left) and B^{07} (right). Biomass was calculated using sector areas at period 1 before any mussel farming footprints were removed. The plots were essentially the same for periods 2 and 3. A regression of log catch on log biomass gives the line drawn and R^2 values.

It can be seen in Figure 6 that variance in the relationship increases with biomass and that the relationship may not be linear. In particular, the two highest annual sector catches appear to depart from a linear trend in the relationship between catch and biomass. However, cell B^0 values range only up to about 570 tonnes and sector B^0 up to 4600 tonnes (mean cell B^0 in any year up to 210 tonnes and mean sector B^0 up to 560 tonnes as shown in Figure 6), and it is the portion of the sector catch to biomass relationship for biomass levels in the range of cell biomass values, where the linearity is best, that we are most interested in for predicting cell catch.

In 3 out of 72 cases shown in Figure 6, sector catch exceeds estimated sector B^0 (left) and in 34 out of 72 cases sector catch exceeds estimated sector B^{07} (right). This can be explained because a time lag between the biomass survey and seasonal fishing gives time for scallops to grow and biomass to increase before being fished so catch can exceed pre-season estimated biomass, , and also biomass is measured with error.

We tested various options for modelling sector biomass and subsequent catch in order to predict catch at the cell level.

3.1.1 Choice of fished area

Biomass estimation depends on the amount of area available for fishing. Before fitting models to catch and biomass we examined the variation in biomass estimates depending on assumptions about fished area.

The amount of fished area and the size of the footprints of marine farming developments over the first three time periods for each of three options of fished area (shown in Figure 4) are given in Table 3. The defined extent of fished area modifies the estimates of available biomass but there is negligible difference in the correlation between biomass and catch at the sector level between the three options (Table 3). Figure 7 compares estimates of $\%C_f^{lost}$ for the first three time periods using each of the three definitions of fished area. Reducing the areas of the Marlborough cells from a wide definition (FA1) to the more conservative definition (FA4) reduced the size of the footprints but had little effect on the resulting estimates of catch loss. Most of the area in FA1 that is not in FA4, such as Admiralty Bay, had low biomass of scallops. Using the survey strata to define the fished area (FA2) gave significantly lower estimates of catch loss for the first two periods but not the third. This was expected as the survey strata were first defined after the marine farms developed during the first two periods were already in place which is why this is not a suitable option for assessing the footprints from these periods. Test results presented in the rest of this report are based on the preferred option FA4 (as explained in Section 2.2.3).

Table 3:The effect of variation in the defined extent of fished area (ha) on footprint area (ha), mean cell biomass (meatweight tonnes) and the correlation between sector biomass and sector catch. Footprint area is shown for footprint option FT1.

	Period 1	Period 2	Period 3
Fished area			
FA1	227 856	225 620	224 540
FA2	209 131	208 506	208 205
FA4	214 871	212 761	212 031
Footprint area			
FT1, FA1	2 236	1 081	4 732
FT1, FA2	626	301	2 995
FT1, FA4	2 110	730	3 740
Mean cell biomass			
FA1	4.28	4.23	4.21
FA2	3.79	3.77	3.76
FA4	3.96	3.91	3.89
Sector C:B R^2			
FA1	0.60	0.60	0.60
FA2	0.59	0.59	0.59
FA4	0.60	0.60	0.60

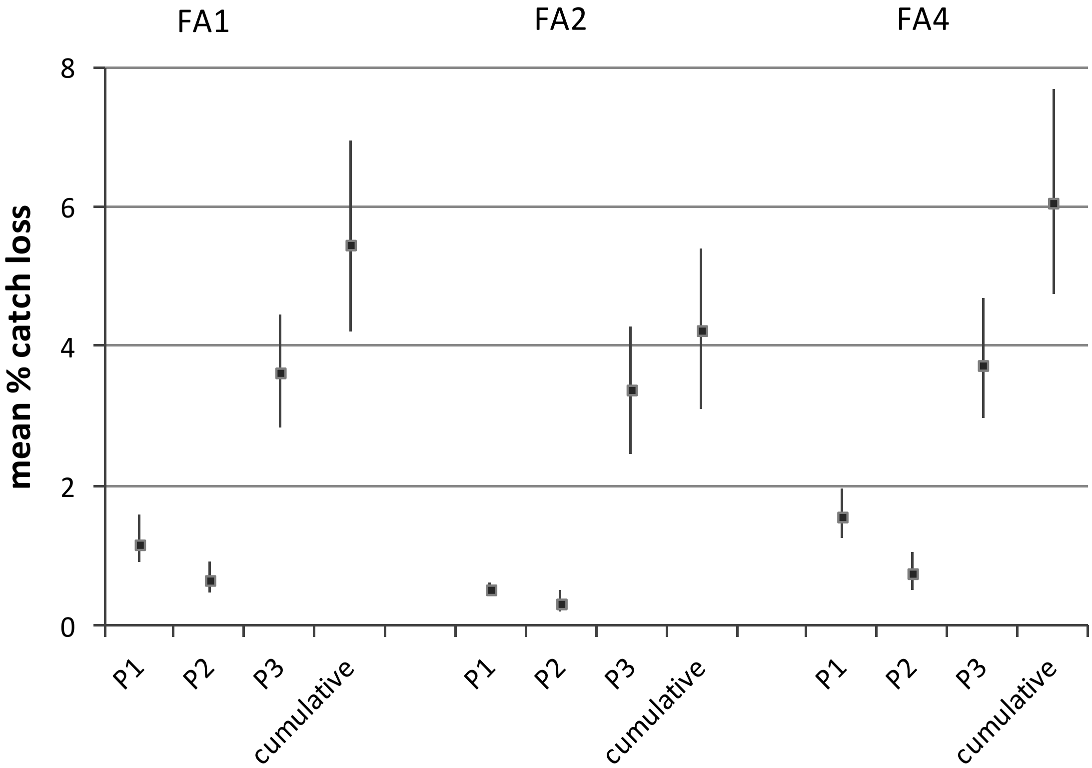

Figure 7: Sensitivity of estimates of catch loss to definition of the extent of fished area. Mean percent catch loss is shown for footprints for past marine farming decision periods P1, P2, and P3, and the cumulative catch loss for each of three fished area options FA1 , FA2 and FA3. Bars are 95% confidence intervals.

3.1.2 Choice of regression model

In any regression model it is important that the residuals be independent and identically distributed (iid) and especially so if the residuals are to be sampled for bootstrapping.

Figure 8 shows example residual plots (in model space, untransformed residuals are shown in Figure 9) for five alternative regression models to explain the relationship between sector catch and the two alternative biomass data sets, in this case for period 1. The residuals are essentially the same for periods 2 and 3 and also for the option of truncating the regression to Bsy <max(Bcsy) although in the latter case the residuals from the linear model are slightly less heteroskedastic. Model D residuals are clearly not iid. Models E, F, G and H are attempts to improve the distribution of the residuals by applying separate regressions by sector (Model E), fitting biomass to $\log_e$ transformed catch (Model F), taking the $\log_e$ of both catch and biomass (Model G) and adding a quadratic term to the $\log_e$ linear form (Model H). Model E gave the best correlation but the residuals were not iid and none of the separate sector-wise components in Model E were significant ($0.03<|t|<0.92$, $0.36<p<0.97$). If we use sector biomass above a threshold density as the explanatory variable the best residuals are in Model G or H. If we use all the biomass the best residuals are Model G.

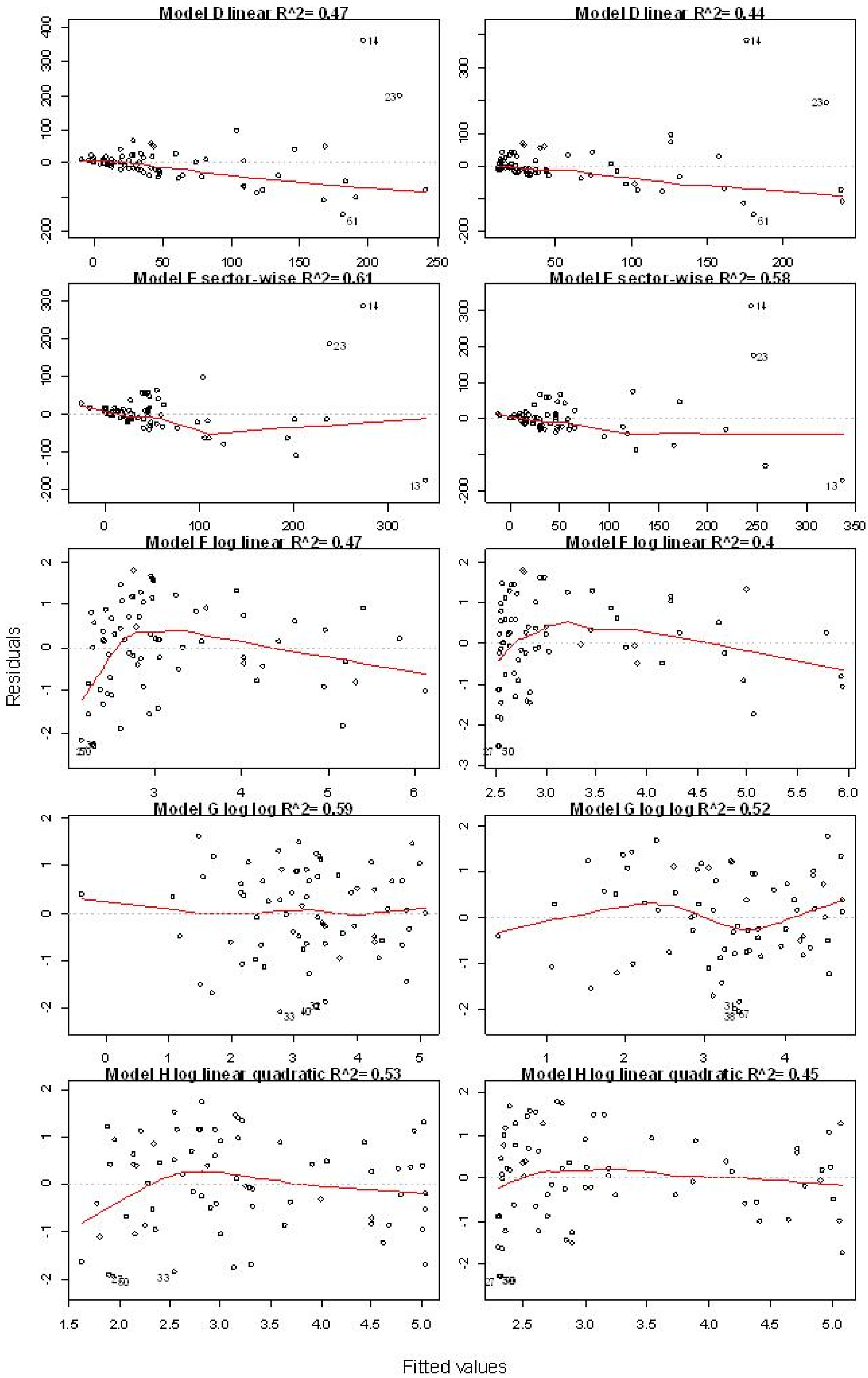

Figure 8: Comparison of residual plots of five regression models for sector catch by mean sector biomass using two different explanatory datasets, B^0 (left) and B^{07} (right). Biomass was calculated using sector areas at period 1 before any mussel farming footprints were removed..

Predicted cell catch for all bootstrap samples and all years and cells combined from Models A to H are shown in Figure 9. Variation in cell biomass estimates in Model A is limited to 236 cell means in each of 16 years and catch estimates are an annual sector specific proportion of biomass. When cell mean biomass is sampled from the distribution of the bootstrapped means the range of cell catch estimates looks like that shown for Model B in Figure 9. Allowing the proportional relationship between catch and biomass to vary by year, sector and level of biomass, and then scaling so that the sum of cell catches within a sector equals the reported sector catch for the year, adds yet more variation to predicted cell catch values (Model C). Model D is the same as Model C except deviation from the mean regression is added to each cell catch prediction before it is scaled and the overall variation in cell catch estimates increases further. Comparing Models D to H shows the result of sampling from residuals in an ill fitting model to predict cell catch. In this case Model G has iid residuals and gives a distribution of cell catch estimates that appear more reasonable than the others.

Indications from Figures 8 and 9 that Model G is the best model to predict cell catch from cell B^0 are supported by the model selection criteria given in Table 4. Model G gives the best AIC, and comparatively good R^2. Model E is over parameterised as penalised with a high AIC. It is interesting that Model G gives very similar results for the estimated catch loss by the period 3 footprint to Model A. This was expected because the reason for adding more components to the model was to better estimate the variance of the means but not necessary the location of μ. Model A is equivalent to a linear regression with $\alpha = 0$ and $= \frac{C_{sy}}{\bar{B}_{sy}}$. It was seen in Figure 6 that the relationship appears to be reasonably linear therefore Model A is expected to provide good point estimates of cell catch (and therefore good point estimates of catch loss for a footprint).

Table 4: Comparison of regression models, coefficients, model selection criteria and results of applying the models to the estimation of percentage catch loss in the period 3 footprint. The 95% interval is the interpercentile range for the 95th percentile of the distribution of bootstrap estimates. Shading shows the preferred option.

Footprint	Model	β	α	Mean AIC	Mean R^2	Median $\overline{\%C_f}$	95% interval
Period 3	A fixed proportion					3.77	0.00
	B bootstrapped					3.78	0.43
	C mean linear	0.45	-7.27	752.2	0.44	4.18	2.73
	D sampled linear	0.45	-7.27	752.2	0.44	2.57	1.99
	E sector-wise			817.9	0.52	2.76	3.19
	F log linear	0.01	2.2	214.0	0.45	2.27	0.86
	G1mean log log	1.04	-1.49	190.8	0.53	4.81	0.50
	G3 sampled log log	1.04	-1.49	190.8	0.53	3.72	1.66
	H log linear quadratic	0.01	2.06	197.6	0.52	2.55	1.06

Comparing the 95% confidence interval for our estimate of $\overline{\%\boldsymbol{C_f}}$ in Table 4 between Models A B C and D shows the incremental effect of including potential sources of variation in a measure of uncertainty in our point estimate of catch loss. It was expected that variance of the estimate would increase between Model C and D because predictions in Model C draw from the mean regression while in Model D predictions include a random residual from the mean. For some footprints the variance of the means is smaller in Model C than Model D and for others it is larger. We explain this as an effect of the residuals not being iid. Model C gives a poor fit confounded by scaling to apply the constraint that $\hat{C}_{sy} = C_{sy}$. A better comparison is between the confidence intervals for mean catch loss from Models A, B, G1 and G3 which serve to illustrate the incremental progression of adding more sources of variation. For these four models, the confidence intervals increase from 0 to 0.45 to 0.55 to

1.72, representing first uncertainty in mean cell biomass, second, some of the additional uncertainty in the relationship between catch and biomass (predicting from the mean regression), and third, adding more of the uncertainty in the relationship between catch and biomass (predicting from the mean plus random residuals).

Model G3 is the chosen estimator of cell catch. It gives very similar point estimates to the simpler Models A and B but incorporates more sources of variance in the measure of uncertainty.

3.1.3 Choice of explanatory variable dataset

Kim and Breen (2005) had shown that removing residual density below a threshold of 0.07 scallops m^{-2} gave improved correlation between biomass and subsequent catch by sector. The R^2 values shown earlier in Figure 6 do not support this previous finding. A comparison of the residuals for various regression models of catch and biomass using either B^0 or B^{07} already seen in Figure 8 also suggest B^0 is the better dataset for predicting catch by sector with the more parsimonious Model G. In Table 5 we further compare these two datasets and also consider the option of limiting the sector biomass dataset to only those values that lie within the range of cell biomass values.

There was very little difference between the models using all the sector biomass data with those where only sector biomass values within the range of cell biomass values were used in the fit (Table 5). The latter gave slightly improved AIC values. Removing residual biomass did not improve the correlation between sector biomass and catch. Note that the R^2 values in Table 5 are the mean of the bootstrapped regressions whereas the R^2 value given in Figure 6 is for the single regression of the mean of the bootstrapped biomass estimates.

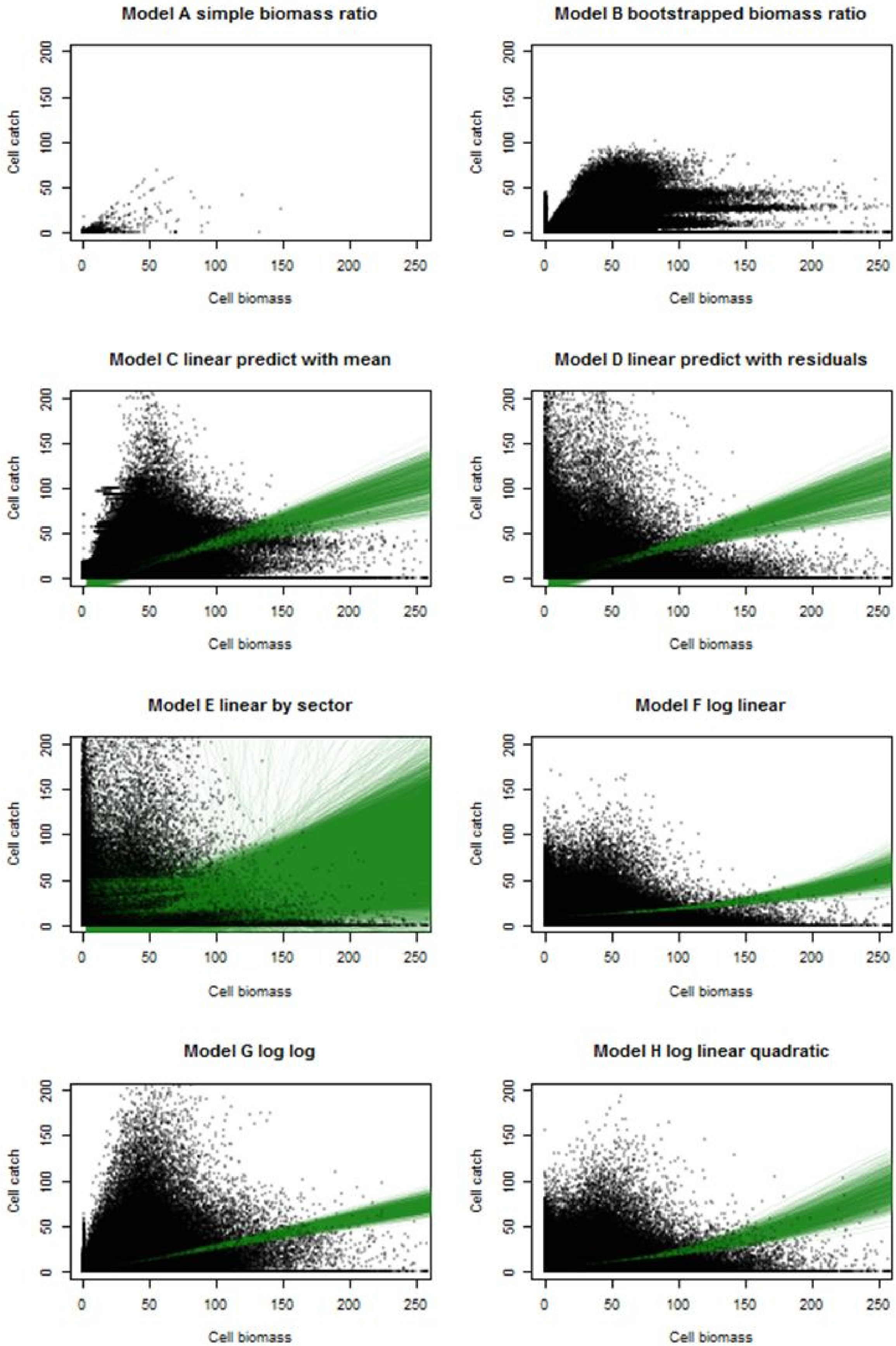

Figure 9: Predicted cell catch from cell biomass in all bootstrap samples, all cells and all years combined.

Table 5: Comparison of model coefficients, model selection criteria, and catch loss estimate for different options of the biomass explanatory variable used in the regression of sector catch on sector biomass. B^0_{sy}, biomass of all recruited scallops in sectors, B^0_{sy}< max(B^0_{csy}), sector biomass values that lie within the range of cell biomass values, $B^{0.07}_{sy}$< max($B^{0.07}_{csy}$), sector biomass above a threshold density of 0.07 scallops m^{-2} that lie within the range of cell $B^{0.07}_{csy}$ values. The 95% interval is the interpercentile range for the 95th percentile of the distribution of bootstrap estimates. Shading shows the preferred option.

Footprint	Fitted data	β	α	Mean AIC	Mean R^2	Median $\overline{\%C_f}$	95% interval
Period 1	B^0_{sy}	1.05	-1.58	196.32	0.57	1.54	0.70
	B^0_{sy}< max(B^0_{csy})	1.04	-1.5	190.61	0.54	1.57	0.70
	$B^{0.07}_{sy}$< max($B^{0.07}_{csy}$)	0.49	1.74	197.52	0.48	1.53	0.84
Period 2	B^0_{sy}	1.06	-1.57	196.53	0.57	0.76	0.56
	B^0_{sy}< max(B^0_{csy})	1.04	-1.5	190.55	0.53	0.76	0.53
	$B^{0.07}_{sy}$< max($B^{0.07}_{csy}$)	0.49	1.75	197.45	0.48	0.74	0.68
Period 3	B^0_{sy}	1.06	-1.57	196.72	0.57	3.78	1.61
	B^0_{sy}< max(B^0_{csy})	1.04	-1.49	190.77	0.53	3.72	1.66
	$B^{0.07}_{sy}$< max($B^{0.07}_{csy}$)	0.49	1.75	197.56	0.48	3.13	1.64

3.2 Estimating Catch at CELL Level

For predicting catch from biomass at the sector level we have so far chosen the following model parameters:

- FA4 is the definition of area available for fishing with which to estimate biomass from scallop density.
- Log log regression model is used to describe the variance in the relationship between sector biomass and catch.
- The explanatory dataset is all recruited biomass in each sector and year where the biomass is less than the maximum cell biomass value.

Applying the resultant predictive model to cell biomass values gives estimates of cell catch. Two further procedural steps that have alternative options are considered next.

3.2.1 Sensitivity to constraints

The procedure used to estimate cell catches demonstrated so far includes two constraints on the estimation of cell catch Firstly, average annual cell catch estimates are constrained to sum to average annual reported catch by forcing cell biomass estimates in areas not surveyed to equal zero. The effect is to assign all reported catch to areas that were surveyed and make no allowance for fishing in areas not surveyed.

. The alternative approach would be to leave the cell biomass data null where survey data was absent. For cells left null no catch estimate is made, for cells assigned zero biomass the estimated catch will also be zero. The effect on the overall result comes when cell catches are averaged over the catch history years. If we leave cells null the effect is to assign the average catch in that cell over the years when it was surveyed. If fishing is assumed to occur only in areas where biomass is surveyed then averaging the cell catches over the years and summing over the cells totals 100%. The alternative gives totalled averages that may exceed 100% of the fishery. The former is a more desirable property in our analysis protocol and in Table 6 we can see that estimates of catch loss are not significantly different between the two approaches.

Secondly, the sum of cell catch within sectors and years is constrained to equal the reported sector catch in each year by normalising model predictions to reported annual sector catch values. The effect was seen in Figure 9 where the variation of cell catch estimates from Model C was large even though they were predicted from a mean regression. Figure 10 shows the effect of this constraint on the predictions made from the preferred Model G. The alternative is to not constrain cell catch estimates which reduces the variance of the estimatesand this is also apparent in Table 6 where the CV of the catch estimates is lower. The effect on estimates of catch loss for three footprints given in Table 6 is not as straight forward. Depending on the footprint the estimated catch loss can be higher or lower by relaxing the constraint but the difference is not great (within 2–13% for the three footprints tests) and is not significant.

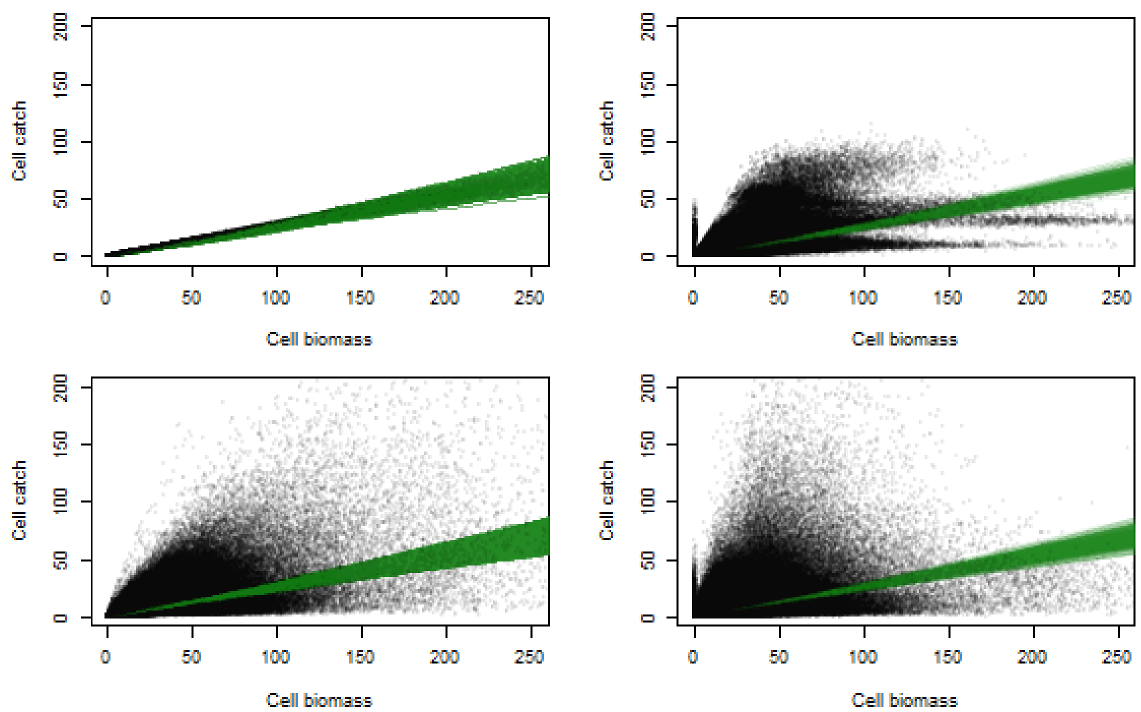

Figure 10: Predicted cell catch from cell biomass in all bootstrap samples, all cells and all years combined using Model G1 (top) where cell catch is predicted from the mean regression and Model G3 where cell catch is predicted from the mean regression plus a random sample from the regression residuals (bottom). Cell catch predictions applying the constraint that $\widehat{C}_{sy} = C_{sy}$ (right) are compared to the case where this constraint is relaxed (left).

Table 6: Comparison of cell catch estimates when constraints are implemented or not. The 95% interval is the interpercentile range for the 95th percentile of the distribution of bootstrap estimates. Shading shows the preferred option.

Footprint	Constraint option	Mean CV $\hat{C}_{csy}$	Median $\overline{\%C_f}$	95% interval
Period 1	missing cell data set to 0	466.0	1.57	0.68
	missing cell data set to NA	464.9	1.59	0.73
	remove C_{sy} constraint	350.9	1.61	0.76
Period 2	missing cell data set to 0	464.7	0.76	0.51
	missing cell data set to NA	465.4	0.76	0.54
	remove C_{sy} constraint	349.8	0.67	0.47
Period 3	missing cell data set to 0	465.4	3.75	1.68
	missing cell data set to NA	465.4	3.77	1.62
	remove C_{sy} constraint	349.8	3.41	1.30

3.3 Measuring percent catch loss

3.3.1 Averaging annual effects

Two comparisons were made in regard to averaging estimates of catch in cells (or catch in footprints). Firstly using a catch weighted average compared to using a simple average of annual proportions . Secondly, comparing different catch history periods to take the average over.

Figure 11 shows the difference between the two alternatives for assessing the average. There are significant differences between the two approaches. The direction of the difference depends on the specific footprint. The choice between the two is not one that can be clarified by statistical means but comes down to the intention of the UAE test. Should areas with higher catches on average be given more value or should areas with higher relative importance each year? Given that catch levels vary markedly between years the catch weighted average favours areas that were fished in the years when catches were high. The alternative gives more value to areas that were important to the fishery in years when catches were low. The former tends to concentrate fishing value into the main areas of the fishery while the latter recognises wider use of space to cover good and bad seasons.

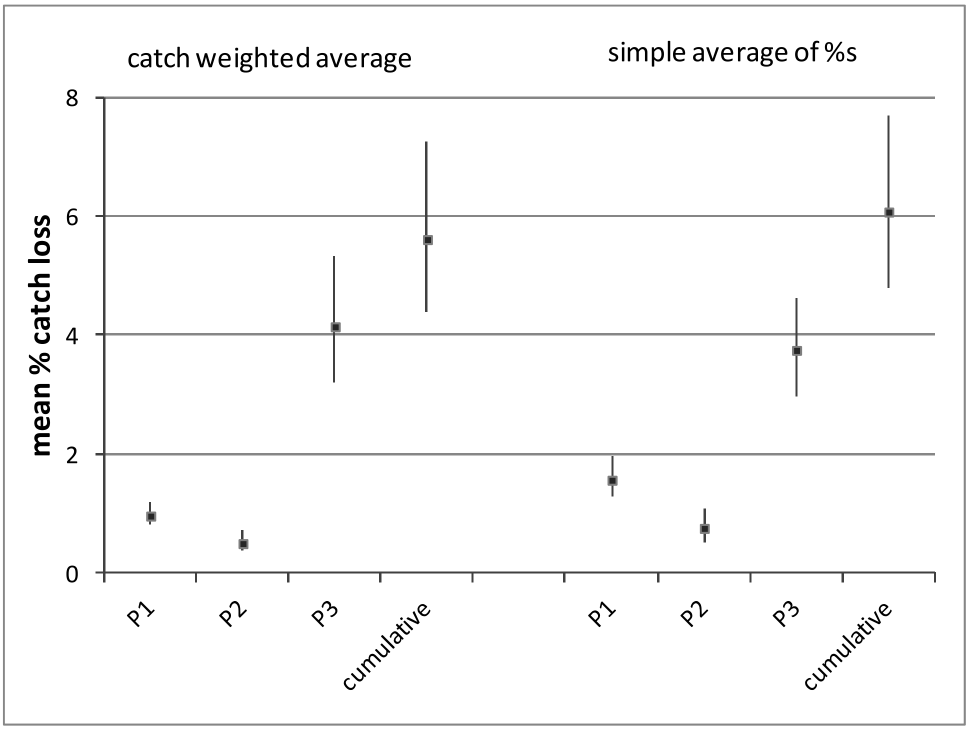

Figure 11: Sensitivity of estimates of catch loss to method of averaging cell statistics. Mean and 95% confidence intervals.

3.3.2 Catch history period

We wish to identify a suitable catch history period for each of the assessments presented here; the assessment of cumulative catch loss from past marine farm decisions over four time periods, and the Tasman IAMA assessment. Assessments for new marine farm proposals use information on fishing in the area of interest prior to development. A period of years is averaged to improve the amount of information used in the estimation and to take account of natural interannual variation in the distribution of scallops and therefore catch. Two matters need consideration, the number of years to average across that reasonably accounts for natural variation in the use of space in the fishery, and which years are likely to best represent the pattern of fishing in the future.

Typical of scallop fisheries, SCA 7 is highly variable in both space and time (Figure 12). As such, a long-time series of data might be expected to give the best estimate of the long-term pattern of scallop catches both in the past and into the future. However, the time-series of survey data shows that the spatial pattern of SCA 7 catch has changed significantly over the last ten years and a long-term average of the past may not be the best choice for predicting an average in the future. Figure 12 shows that catches in Tasman Bay declined to very low levels after 2004 and have not recovered in the eight years since. The Golden Bay fishery declined over the same time period but a little more gradually.

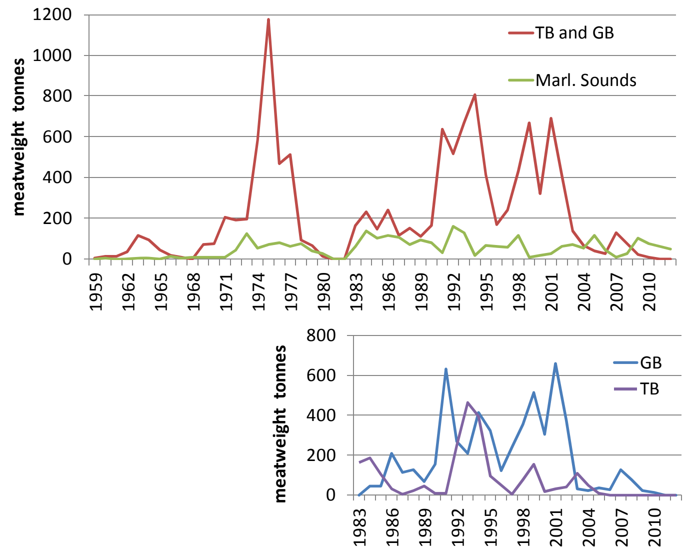

Figure 12: Annual landings in the Challenger scallop fishery since records began. Landings were reported separately for Tasman bay (TB) and Golden Bay (GB) only since 1983.

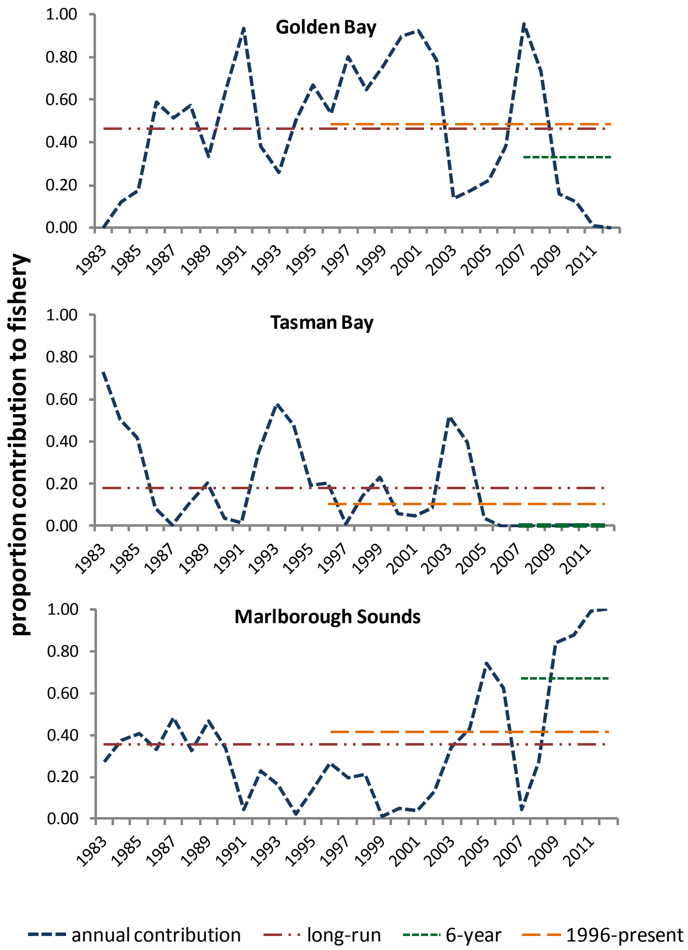

Figure 13: Comparison of summary statistics for measuring the relative importance of each of the three main regions in contributing to the total landings in the Challenger scallop fishery. Averages based on different catch history periods are shown as horizontal lines over the supporting time period.

Our estimate of displaced fishing is governed by the spatial distribution of $(\overline{\%C}(ha)^{-1})$. The relative contribution of the main regions of the fishery can be seen in Figure 13 showing that for six out of the last eight years the Marlborough Sounds has contributed the most catch.

On a finer spatial scale, of more relevance to the UAE test, the location of scallop beds varies more greatly than suggested by the regional statistics. The mean density of scallops in the grid cells varies markedly from year to year (Figure 14). In the 17 year time-series of grid cell mean densities shown in Figure 14, the longest time gap recorded between occurrences of relatively dense scallop recruitment in any grid cells is 7 years. More common cycles of recruitement are between 2 and 5 years. Many areas of the fishery, including all of Tasman Bay have not produced scallops in the last 8–10 years. There is no evidence from the past that indicates that the latter areas will ever recover.

We conclude that a catch history period of at least 5–7 years is needed to ensure that episodic catches of scallops are reasonably represented in the average catch statistics of any area.

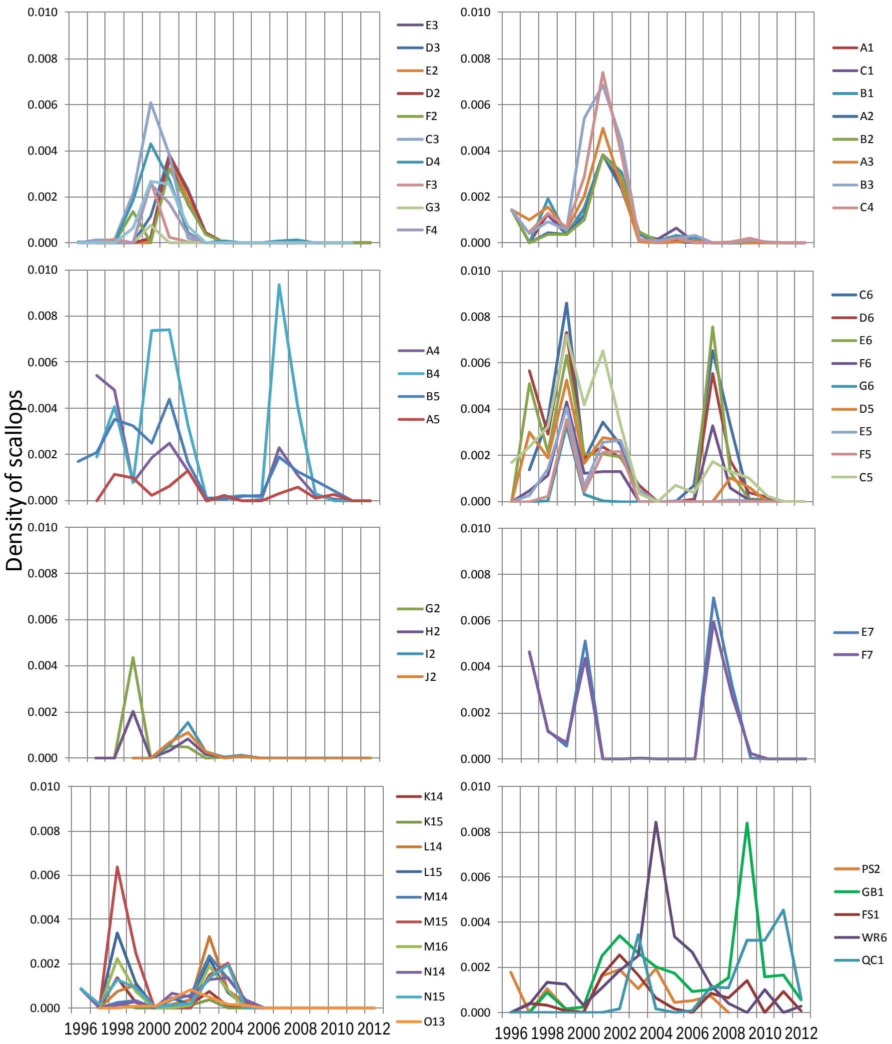

Figure 14: Temporal patterns in annual density of recruited scallops ($\bar{M}^{0.07}$in kgm^{-2}) in a selection of individual grid cells over 17 years grouped by similar temporal patterns for Golden Bay (top six graphics) and by area for Tasman Bay (bottom left) and Marlborough Sounds (bottom right).

The history of scallop enhancement and rotational fishing in this fishery also needs to be taken into consideration for defining a suitable catch history period. In a rotationally managed fishery the catch history period should be a multiple of the rotational cycle, in this case 3 years, so that relativity is maintained between areas. Rotations have not always been strictly implemented in the fishery depending upon the success of annual enhancements. In the last eight years, the factors that have led to poor natural scallop productivity have also given poor enhancement results. Nevertheless, the enhancement company has continued to release scallop spat to areas of Tasman and Golden Bays and three year rotational fishing may be reinstated.

We considered whether there was a statistical framework to guide the decision of catch history period. Time-series analysis techniques such as ARIMA models or Kalman filters would be useful if the purpose was to predict the next few time periods, but this is not the objective here and time- decay methods do not appear to be useful in this case. We considered whether to use a test of significance for the linear trend in each area as the basis of a choice between a long or a short term catch history period, where a significant trend would result in the choice of a short-term average. However, fitting a linear trend to mean densities at the cell, sector, or regional scale gave varying results. Also, with highly variable scallop catches, linear trend lines are overly influenced by the most recent data point. The patterns of change seen in Figure 13 are visible by eye but not easily gauged mathematically.

In our judgement, the SCA 7 fishery has changed to the extent that a long-term average of past fishing patterns no longer best represents likely future patterns. Tasman Bay is unlikely to contribute to the fishery in the foreseeable future. Golden Bay will hopefully recover but this is uncertain and it is likely that the Marlborough Sounds fishing grounds will be the major contributor to the fishery for the foreseeable future. This advice should be offered to the decision maker together with assessments based on a range of catch history periods so that the consequences of choices based on uncertain information can be evaluated in decisions..

From the considerations presented here we recommend 6 and 9 years and the full length of the available time series, presently 16 years, as a suitable range to present to decision makers. Six years is considered the minimum period to account for natural variation in the scallop fishery and short enough to place most value on the presently important fishing grounds. Nine years is the next option that is a multiple of three and offers a longer term to incorporate natural variability. Sixteen years gives the longest summary available at this point in time and over this long, and given the erratic rotations adopted by CSEC, it is not so critical that it be a multiple of 3.

In the case of the assessment of cumulative effects of all existing farms the task is made easier by the fact that at least some of the future annual distribution of fishing affected by these developments is known because it has already happened. The present assessment of the cumulative effects of existing marine farms, covers a period of consent applications beginning in the 1970s up to 2006. The assessment can be made for the whole cumulative footprint using a single catch history period or stepwise using different parameters for different time groups of decisions. Over the relevant time period there was no evidence of a long-term trend in the spatial distribution of fishing effort between the main regions of the fishery until the unusually long absence of scallops in Tasman Bay started to become apparent in the late 2000s. Therefore a long-term average of annual fishing patterns is considered appropriate to characterise this entire period.

Most of the marine farm developments included in the cumulative effects estimate have been in place since well before the late 2000s and the effects of these developments occurred over a time that we consider is best represented by the average of all the years for which there is spatial data available and that is 1997 to 2012. We cannot conceive of a reasonable alternative to summarising the whole time period of survey data to represent the average pattern of spatial occupation of fishing that has been affected by all past decisions. However, in doing so we assume that the fishing in each cell after a footprint takes effect was similar to that before the footprint effect but reduced by the proportion of the footprint area in the cell. This assumes that the footprint has not become so large that the cell becomes no longer worth surveying or visiting by fishers. Currently the proportion of the cumulative footprint in cells ranges up to 48% and the histogram of effects is shown in Figure 15. In the Marlborough Sounds, where cells may become unattractive to visit, the maximum loss so far is 30%

in Port Ligar and Waitata Bay. Up until 2012, all cells affected by marine farming have continued to be surveyed.

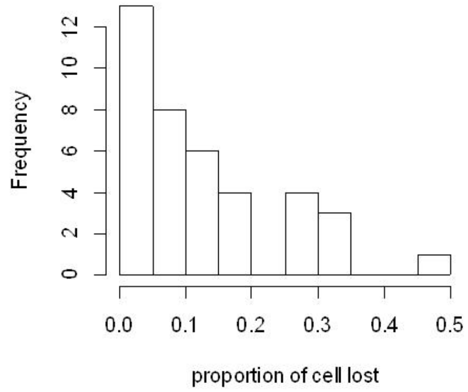

Figure 15: Frequency distribution of cell proportions lost to existing marine farm footprints including seasonal farms and not including unaffected cells.

3.3.3 Aggregating displaced catch

Applying the three methods of aggregating UAE estimates to four incremental test footprints, each 25% of the starting cell areas, gave identical results of 25, 50, 75 and 100% cumulative effects respectively, as expected. There are negligible differences between the three methods of aggregating cumulative UAE estimates when applied to the existing farm footprints (Figure 16).

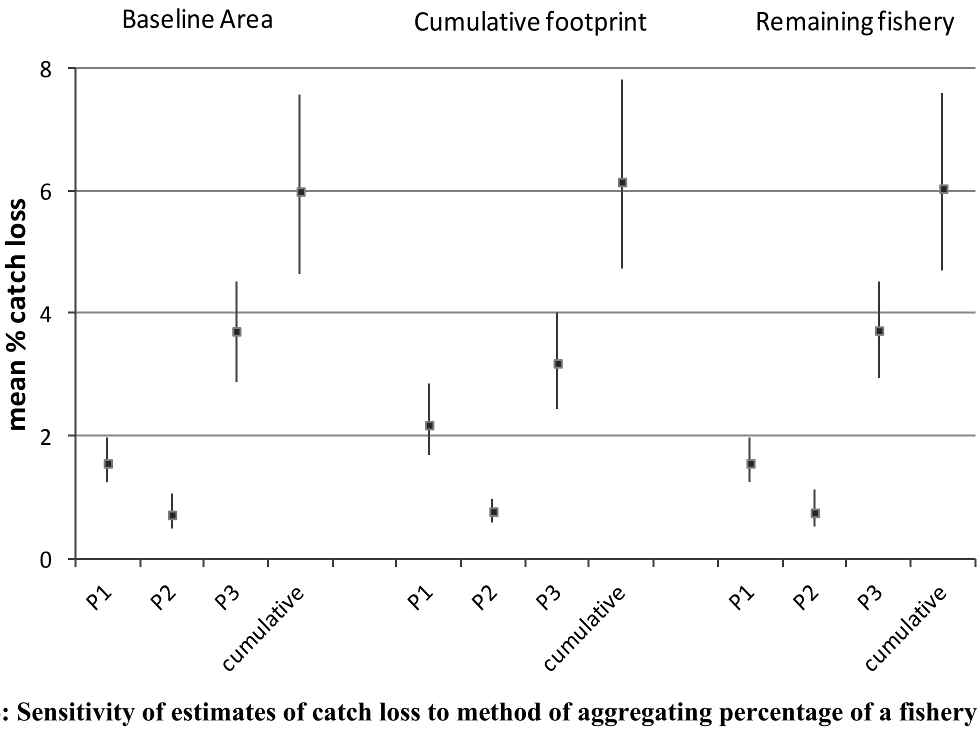

Figure 16: Sensitivity of estimates of catch loss to method of aggregating percentage of a fishery affected. Mean and 95% confidence intervals.

The baseline area method requires that a different cell area parameter be used for calculating footprint proportion in a cell than that used for calculating the biomass available in a cell. Also cell area available for fishing may change over time for reasons other than marine farm development. These factors potentially complicate the use of this method.

The cumulative footprint method is problematic as it reassesses past decisions and may give different results for past effects that have already been mitigated. It could result in an incremental footprint producing a catch gain rather than loss and could see the cumulative effects sea saw around the “undue” threshold. This is illustrated by the comparative difference in the estimated effects of the fourth footprint (Tasman IAMA) shown in Figure 16. The other two methods apply a different catch history period to the fourth footprint but retain the previous estimates as originally assessed. The cumulative footprint method reassess all the previous footprints using the catch history period of the fourth assessment. The result is that the estimates of the previous footprints increase (not shown in Figure 16 but they are 4.3, 0.6, and 4.2% respectively) and therefore the cumulative effects estimate increases and all this increase is attributable to the fourth footprint. The outcome is that the effect of the fourth footprint is overestimated. Under different conditions the outcome could be an underestimate.

For these reasons the remaining fishery method is preferred. The cumulative effect to date is monitored and readily available as a parameter. The cell area parameter is always the current cell area available for fishing. The individual footprint effects can be added to give the cumulative effects to date. Past assessments are not revisited unless a past footprint is altered by a farm being disestablished.

3.4 Cumulative assessment up to present

We have assessed the cumulative catch loss of all existing marine farms using the preferred choice of protocol options explained in previous sections. In summary these are:

- Fishery area definition is FA4.
- Biomass dataset for predicting C_{csy} is B^0_{sy}< max(B^0_{csy}).
- Log log regression model for predicting C_{csy}.
- Constraints in predicting Ccsy are missing cell biomass data =0, and $\hat{C}_{sy} = C_{sy}$.
- Catch history period for assessment of all existing farm effects is 1997 to 2012 inclusive.
- Annual percentage catch by cell is aggregated with a simple average of percentages.
- Percent catch loss is based on the remaining fishery so they can be summed to cumulative percent loss.

The nature of the footprints that make up the cumulative assessment of all existing farms is given in Table 7 and the catch loss estimates are given in Table 8.

Table 7: The number and combined size of successful marine farm applications made within four time periods. The corresponding areas of two versions of the footprint of these farms for effects on scallop dredging are also given. A few farms have been issued for seasonal use only and the nature of the footprint for these farms is still under consideration so it is presented separately.

Period	Dates	Seasonal	Farm decisions	Farm area (ha)	Footprint area (ha) (FT1)	Footprint area (ha) (FT2)
P1	up to 30/09/92	No	388	1 468	2 110	1 996
P2	1/10/92 to 31/03/96	No	98	399	730	660
P3	1/04/96 to 19/01/06	No	448	2 792	2 755	2 316
P3s	1/04/96 to 19/01/06	Yes	5	841	985	985
P4	20/01/06 to 31/03/13	No	16	470	30	37
Total	up to 31/03/2013	Both	955	5 970	6 610	5 994

Table 8: Comparison of catch loss estimates for four alternative time periods and two alternative footprints describing the area from which scallop dredging is excluded by all existing authorised marine farms within the SCA7 fishery. The 95% interval is the interpercentile range for the 95th percentile of the distribution of bootstrap estimates. P3s indicates the separate footprint for the seasonal farms granted in period 3.

Footprint (*f*)	Median $\overline{\%C_f}$	95% Interval	Median $\overline{\%C_{cum}}$ (Total)	95% Interval (Total)	Median $\overline{\%C_{cum}}$ (TIAMA)	95% Interval (TIAMA)
P1_FT1	1.56	1.26-1.96	1.56	1.26-1.96		
P2_FT1	0.76	0.54-1.08	2.32	1.80–3.04	0.76	0.54–1.08
P3_FT1	1.83	1.47-2.24	4.14	3.27–5.28	2.59	2.01–3.32
P3s_FT1	1.92	1.24-2.81	6.06	4.51–8.09	4.51	3.25–6.13
P4_FT1	0.03	0.02–0.05	6.09	4.53–8.14		
P1_FT2	1.47	1.16–1.85	1.47	1.16-1.85		
P2_FT2	0.71	0.49–1.03	2.18	1.65-2.89	0.71	0.49–1.03
P3_FT2	1.57	1.25-1.97	3.75	2.89-4.86	2.28	1.74-3.01
P3s_FT2	1.93	1.24-2.76	5.68	4.13-7.61	4.21	2.97_5.77
P4_FT2	0.03	0.02–0.05	5.71	4.15-7.66		

Based on the procedures discussed so far, the cumulative effect of marine farming to date is about 6.09% of the fishery if the seasonal spat catching areas are included in the marine farming footprint. In this case, we can be 95% certain that the effect lies between 4.5 and 8.2%. Of this about 4.51% must be taken into account when assessing the Tasman IAMAs due to the transitional legislative provisions governing that particular case.

These estimates are sensitive to the amount of area deemed to be excluded from scallop dredging with an 6.5% difference between the FT1 and FT2 footprints giving cumulative catch loss of 6.09 and 5.71% respectively (Table 8). Additionally 1.92% of the 6.09% estimated cumulative effect comes from the large seasonal spat catching consents for which the effect on fishing is disputed by marine farmers.

The difference between the footprint sizes comes from different interpretations between analysts of what area dredging is likely to be blocked from given the presence of the existing marine farms. The FT1 footprint was developed in 2006 with consultation with commercial fishers. FT2 is a more recent interpretation after review of the previous work. The difference between the two point estimates lies within the range of 95% confidence of where the true statistic lies. Consultation with affected parties will lead to a decision on the final shape and size of the footprints.

3.5 Assessment of the Tasman Interim AMAs

The Tasman IAMAs were implemented by the Tasman District Council in their Regional Plan and are shown in Figure 17. We present here the results of applying the described technical protocol to a preliminary footprint of the AMA. The final size and shape of the footprint is yet to be determined as it will take into account any permanent navigation laneways or fallow areas between farmed areas where MPI can be satisfied that scallop fishing will not be affected. For simplicity we have assumed here that the whole AMA will become closed to fishing.

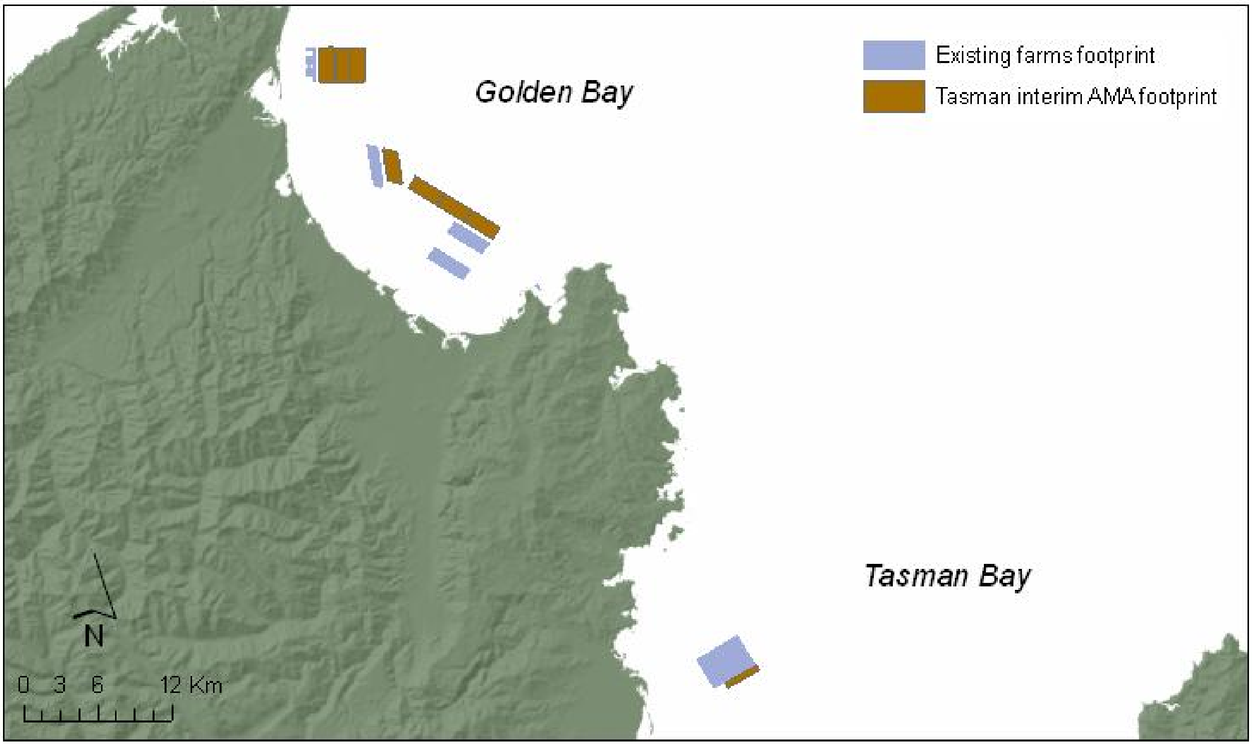

Figure 17: Location of the Tasman Interim AMA footprint.

The AMAs comprise 2109 ha giving a footprint of 2475 ha. Three options of catch history period are presented in Table 9 showing that the result is highly sensitive to choice of this parameter. The preliminary indication of the effect of the Tasman IAMAs ranges from 0.7 to 2.4% depending on which catch history period is used to represent the spatial pattern of fishing in the future. On top of the existing cumulative effect (including the seasonal sites) this gives a catch loss of between 0.8 and 2.5% that must be settled by agreement between the parties.

Table 9: Preliminary assessment of the catch loss in the SCA 7 fishery likely to be caused by the Tasman IAMAs estimated with three alternative catch history periods and assuming an existing cumulative effect of 4.21% as given in Table 8. The 95% interval is the interpercentile range for the 95th percentile of the distribution of bootstrap estimates.

Footprint (f)	Footprint Ha (A_f)	Catch history period	Num. years	Median $\overline{\%C_f}$	95% Interval	Median $\overline{\%C_{cum}}$	95% Interval
AMA option 1	2474	1997–2012	16	2.39	1.96–2.93	6.61	6.6–8.7
AMA option 2	2474	2004–2012	9	1.09	0.77–1.55	5.30	3.74–7.32
AMA option 3	2474	2007–2012	6	0.68	0.37–1.27	4.89	3.34–7.04

Fishing Intensity ($\overline{\%C}(ha)^{-1}$) for the three options of catch history period are shown in Figure 18. Figure 18 (bottom) shows the long-term average pattern of relative importance of fishing grounds which has been used in this report to assess the effects of all marine farming applications made up to January 2006.

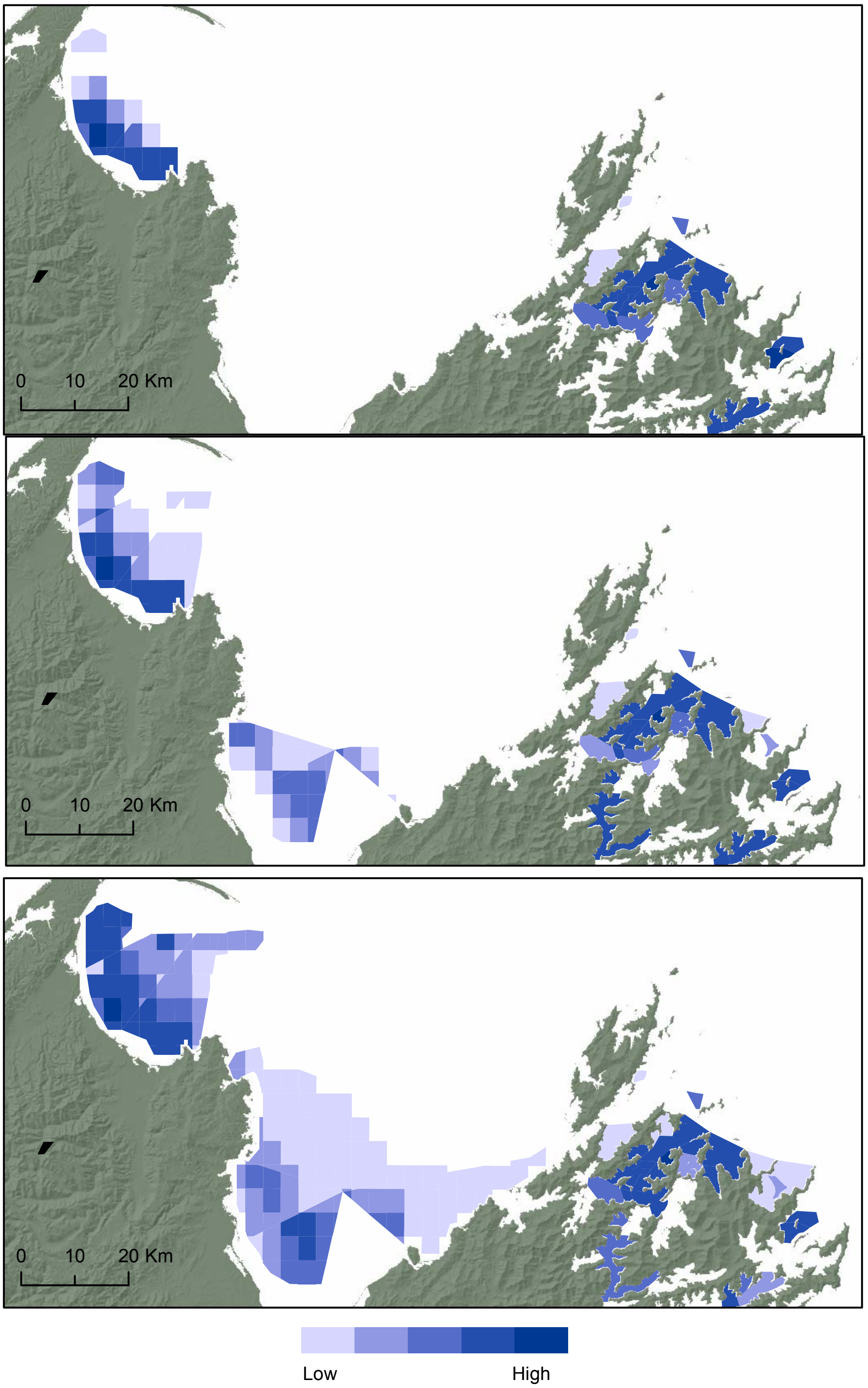

Figure 18: Fishing Intensity averaged over 6 years (top), 9 years (middle) and 16 years (bottom).

4 DISCUSSION

We have developed a protocol that can be seen diagrammatically in Figure 19. It involves firstly, estimating the spatial distribution of commercial scallop catch and secondly, using that to calculate a metric for the relative importance to the fishery of catch displaced from a given footprint. It starts with estimates of mean meatweight of recruited scallop density from annual pre-season scallop surveys post-stratified to a set of cells covering a suitable area definition of the commercial SCA 7 fishery.

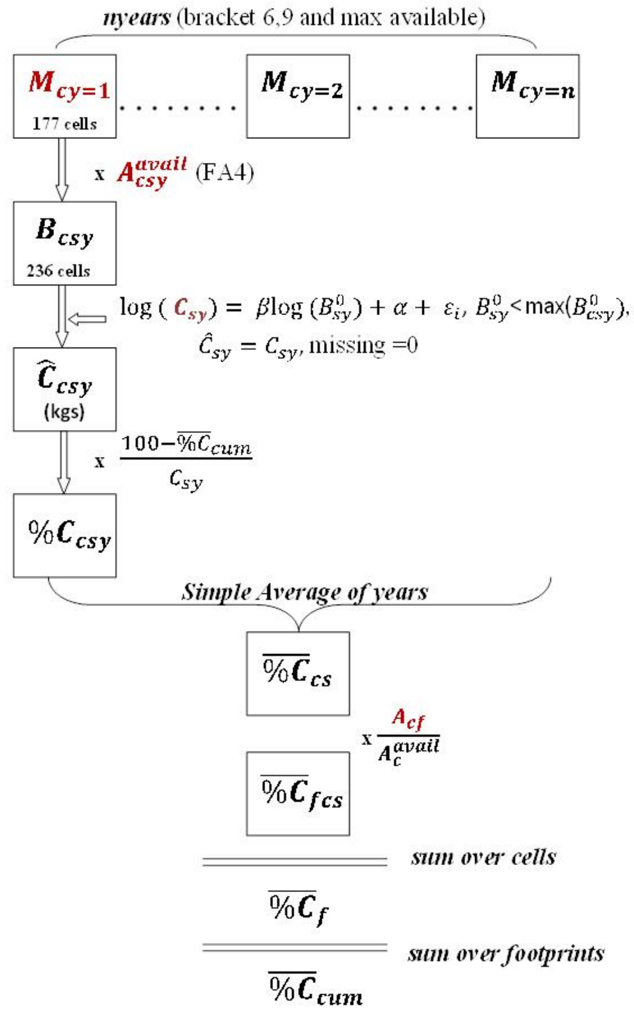

Figure 19: Diagrammatic view of analysis protocol for estimating the percent catch loss, $\overline{\%C_f}$ in the SCA 7 fishery from a footprint *f* and cumulative loss from all footprints, $\overline{\%C_{cum}}$. Five input parameters, shown in red, are M_{cy} the mean meatweight density of scallops (kgm^{-2}); A^{avail}_{csy} the area available for fishing in each cell *c*, sector *s* and year *y*; *nyears*, the catch history period; C_{sy}, reported catch by sector and year; and A_{cf}, the area of the footprint in the cell. A key step is estimating catch from cells, $\hat{C}_{csy}$ using mean biomass from cells B_{csy} and the relationship between reported catch and biomass in sectors.

The sensitivity of estimated catch lost from the cumulative marine farming footprint to a choice of three fished area definitions has been presented here and our preference explained. This is a general parameter than can be stated in advance of all assessments and is unlikely to be modified for an individual assessment. The choice will be finalised in consultation with stakeholders. The definition used for each future UAE test will be stated in the UAE assessment report with reference to this report and any chosen variation explained.

Any new areas fished will be added to the cells or new cells added when information becomes available and particularly if new areas are added to the pre-season scallop surveys. Survey strata may change from year to year and improved information on where fishing occurs may become available from finer resolution reporting. There is no reason why future assessments need to continue to use the grid cells used here. Polygons of uniform density or density contours of any shape or size can be used to represent the best available information in any one year and combined with other years to form annual average surfaces.

If an area is not surveyed it is assumed it is not fished (given effect by the constraints applied to estimation of cell catch). The areas surveyed are designed by CSEC and responsive to the knowledge of the fishers about where they have found scallops in the past. An alternative approach circumvents making this assumption by only assessing the displacement of fishing as a proportion of fishing that occurs in surveyed areas and ignoring any fishing outside those areas. In effect the result is little different. We prefer to constrain cell catch estimation with the best information available including actual sector catches and accepting that surveyed areas are the most likely areas fished.

Available biomass for fishing in a cell in any given year is a product of cell meatweight density from that year's survey and cell area available for fishing in April of that year after footprints of aquaculture decisions made up to that time have been removed. Catch from each cell in each year is predicted from a model of how catch is related to available cell biomass and reported catch in the surrounding sector each year (Model G3 presented here (Table 2 and equation 6)).

In future years, additional information on where fishing occurs can be incorporated into the model that predicts catch in a cell. For example fine spatial resolution reporting of fishing events could be used to map catch distribution to an appropriate cell grid to replace the estimation of catch based on biomass. This would greatly improve the precision of catch per cell estimates.

The average importance of each cell in the remaining fishery is calculated as the simple average of the proportions of the fishery taken from each cell each year adjusted for the cumulative percent catch loss already incurred (the remaining fishery is defined as 100% less cumulative percent catch loss already incurred).

The number of years to include in the average is a choice requiring judgement by the decision maker. Given the significant changes in the spatial extent and location of fishing over the last 10 years our estimator is highly sensitive to the choice of catch history period. We cannot provide an objective answer to the question of the best catch history period to use for an assessment. The long-term average may be the best if recent changes are reversed over a long-term cycle. However, we believe either 6 or 9 years is a reasonable choice given present knowledge of the ecology of the fishery. Until such time as an accepted standard is set, estimates of catch loss based on the most recent 6 and 9 years and all available years should be presented in the UAE report. For any period of time where annual biomass surveys of SCA 7 are not available we recommend using periods of at least 6 years in the available time-series of annual surveys that most closely match the recent sector catches in the fishery.

The calculations up to this point will be updated each year in April and incorporated into a GIS-based analysis tool. Applying the tool for a UAE test involves multiplying the average importance metric for each cell by the proportion of the available fishery area in each cell that occurs in the given footprint, and summing over the cells in the fishery. The outputs are the estimated percentage of the fishery that will be lost from the proposed marine farm(s) and the cumulative percentage of the fishery lost to date from all previously authorised marine farming.

The specific shape and size of the footprint of assessed marine farms will be drawn up by an MPI analyst giving consideration to any submissions received by the applicant or affected parties. The general rules stated in Section 2.2.4 of this report will be referenced and adopted unless otherwise stated. A diagram of the footprint should be included in the assessment report. Here we found that estimates of catch loss are sensitive to the amount of area deemed to be excluded from scallop dredging. Differences between analysts in applying consistent rules for defining footprints gave 6.5% variation in estimates of the cumulative effects to date (6.1 and 5.7%).

This analysis protocol gives outputs which can be accepted as the best use of available information until such time as better sources of information, particularly on the location of fishing become available. The outputs can be accepted as accurate (non-biased) in the long-run within the given bounds of uncertainty. By long-run here we mean that the more marine farming decisions made, the larger the cumulative footprint becomes and the closer footprints will come to occupying whole cells or areas approaching the sampling intensity of the original survey strata. At increasing scales of cumulative footprint the assumption of uniform distribution of catch across cells becomes less important. However, while the sum of many estimates of loss from small footprints may give a reasonably accurate estimate of cumulative loss, the precision of an estimate of catch loss from any individual small footprint may be low. The true catch loss for any small footprint will most likely lie somewhere in the range of zero to the catch that could be taken from the average of the highest mean density recorded for sample tows within that cell. While this may seem highly uncertain grounds for supporting decisions on the effect of individual marine farms on the scallop fishery, especially when the threshold is exceeded and an aquaculture agreement is required for a farm to proceed, it is fair and reasonable in the long-run.

Precisely estimating the effect of excluding scallop dredging from a small area in terms of the loss of average annual catch is a difficult task for a number of reasons. Any assessment of future effects from a proposed change requires good information about the current state and prediction of the likely future state. Accurate prediction requires a well informed model. In the case of the SCA 7 fishery the task is made feasible by the fact that there is, comparatively, very good data on fish distribution and abundance in this fishery. Furthermore, in this fishery the task of predicting future catch loss is simplified by adopting the reasonable assumption that all catch displaced is effectively lost to the fishery because it cannot be made up from underutilised fishing opportunities elsewhere. In essence the task amounts to using past average catches to represent future average catches and a procedure for estimating the past average catch from the area of a marine farming footprint.

Estimating catches taken each year from a small area requires some unavoidable simplifications in a model of the spatial distribution of scallop catch. We strive here to make the best use of all available data and to incorporate variance in measured observations wherever possible. Nevertheless, the estimation procedure described here is subject to some necessary assumptions.

Firstly, we assume the regression model for estimated sector biomass and subsequent sector catch (6) adequately represents the variance in the relationship between cell biomass and subsequent catch even though the regression coefficients were derived from observations at the sector level. The range of catch and biomass observations used to fit the model cover the range for individual cells so the regression has not been extrapolated beyond the range of the observations. It was seen in Section 3.2.1 that incorporating the constraint that the sum of predicted cell catches in a sector must equal the reported catch from the sector increases variance in cell catch predictions by about 33%. Therefore the expected increased variance at the cell levels is taken into account.

Secondly, we assume that our estimator of mean cell density is not biased by non-random sampling of cells in the cases where cell area is much larger than sampled area. We attempt to minimise this potential source of bias by reducing cell areas to the area surveyed.

Of greater effect is the assumption that mean density has a uniform spatial distribution within cells so that the cell mean is a non-biased estimator of the mean of any small part of a cell. When estimating the effect of a large footprint, for example all marine farming up to the present, this assumption will not be as critical as when estimating the effect of any small footprint such as a single marine farm application of a few hectares.

A few matters that may deserve further attention include the assumptions that:

- catch is a suitable measure of fishing. Using catch as a measure of the amount of fishing is an approximation that is likely to undervalue fishing grounds close to port where effort may be disproportionately higher than catch due to lower costs of fishing.
- the worst case scenario of fishing displacement is that all displaced catch is lost. Increasing competition between fishers for remaining space may increase the costs of fishing more than if the displaced fishing effort was retired.

Validation of this technical protocol has been attempted by firstly ensuring the analytical methods have been implemented correctly in the computer code used to apply them and secondly, examining the accuracy of the estimator, qualifying it with assumptions, and identifying any possible sources of bias and the risks associated with these. Thirdly we have provided a measure of the precision of the estimates as a guide to their usefulness for supporting decisions.

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APPENDIX 1

The following is a summary of relevant issues raised in early reviews and during implementation of the original scallop model (Ministry of Fisheries, 2006).

A. Outstanding matters from the 2006 peer review.

The original scallop model was presented to the MPI (then MFish) Shellfish Working Group on 15 March 2006 where it was noted that the model logic was appropriate to answer the question of the effect of alienation of space. Recommendations included:

A1. Modification and clarification of some equations in accordance with the review of Breen (2005).

A2. Estimate should be unbiased and neutral.

A3. Use more than one year's data.

A4. Must include uncertainty envelopes when used to inform decisions.

A5. A revised model should be presented to the working group.

B. Matters raised in subsequent peer reviews.

During the years 2009–2012 the Ministry's UAE assessment on the Tasman Interim AMAs was reviewed during High Court and Court of Appeal proceedings and the following issues were raised:

B1. Confidence intervals may be large for small footprints and the model outputs should not be used to compare the mean value of different areas without an estimate of the variance of the means to determine if differences are statistically significant.

B2. The original model suggested that two averaging options should be presented as though they were both valid models and the range of their outputs was informative. One was to average losses from cells over all years, the other was to average losses from cells over only the years when that cell was open for fishing. All years must be used in the annual average value of a cell not just the years when that sector is open to fishing.

B3. The value of some areas shows a declining trend for example the value of the AMA footprint each year from 1997 to 2005 showed a statistically significant linear trend. In such cases a long-term average is not the best predictor of the future value.

B4 The model should be updated with data from the most recent years.

C. Relevant legal points decided by the High Court and Court of Appeal.

C1. Must exclude farms granted prior to 1 October 1992 from assessment of the cumulative effects of existing farms.

C2. Only marine farms that have or are likely to be developed should be included in the assessment of cumulative effects.

C3. The buffers used for footprints are a matter for the Ministry to decide.

C4. The model should be updated with data from the most recent years.

C5. The Ministry's decision on a 5% threshold is appropriate.

C6. Only area proposed to be occupied with structures should be included in footprints i.e. navigation lane ways if permanent should be excluded from footprints.

D. Matters subsequently identified during implementation.

D1. As the time-series gets longer, is it best to use the longest time-series available? What is the best catch history period?

D2. How should we handle the situation of new areas being surveyed and fished in future years.

D3 Include 7LL in the model as this is now fished.

D4 How should we modify the protocol in the case of missing years in the survey time-series.

D5. The original model used sub-sector catch information collected by CSEC for sectors 7JJ and 7KK based on biotoxin monitoring areas. This data was not available for updating the model so we reverted to using sector catch data.

D6. Need to identify the location of important fishing grounds not just the location of all possible fishing territory otherwise the value is diluted.

D7. Rearrange the equations to calculate and map fishing intensity as the mean % of the fishery per ha in order to automate the protocol in a GIS.

D8. Need to formalise a method for updating the cumulative effect with each new marine farming decision.

D9. Need to present for peer review the implementation of the protocol (and shortcuts taken) for the cumulative assessment of all existing marine farms of SCA7.

APPENDIX 2

Reported landings

Fyear	7A	7B	7C	7D	7E	7F	7GH	7I	7J	7K	7L
1996	111	12	0	11	0	36	0	0	0	60	1
1997	0	40	199	0	2	0	0	0	0	58	0
1998	94	187	0	0	17	0	61	71	0	117	0
1999	0	92	421	28	88	26	13	1	0	7	0
2000	39	163	91	5	13	0	0	10	0	16	0
2001	50	559	44	0	0	6	25	7	0	25	0
2002	100	218	45	0	0	4	34	7	0	62	0
2003	28	0	0	0	0	96	11	0	0	52	18
2004	4	16	0	0	17	26	3	0	0	51	0
2005	10	24	1	0	0	4	1	0	0	94	22
2006	13	13	0	0	0	0	0	0	1	41	0
2007	0	0	128	0	0	0	0	0	0	0	6
2008	0	75	0	0	0	0	0	0	0	28	0
2009	2	13	4	0	0	0	0	0	0	97	4
2010	0	10	0	0	0	0	0	1	0	57	17
2011	0	0	1	0	0	0	0	0	0	30	30
2012	0	0	0	0	0	0	0	0	0	25	21

Grey cells were used for regression model (3)