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Development of robust methods to estimate acceptable levels of incidental catches of different commercial and by-product species.

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1 Executive Summary

There were three primary objectives of this work:

1. Develop guidelines and tests to determine if incidental catch levels for any species are likely to be unsustainable or contrary to the principles of the Harvest Strategy Policy, with particular reference to species under rebuilding strategies and provide case examples.

2. Conduct risk assessments to determine acceptable levels of incidental catch TACs for species under rebuilding strategies within the parameters of the Harvest Strategy Policy.

3. Determine whether any of the methods developed under objectives 1 and 2 can apply to relatively data poor species; develop guidelines for application to species for which there is only catch data.

In addition there was an objective to determine whether the ideas developed here could be applied or used with TEP species. Only some commentary towards that idea were expressed and this was not pursued further.

Guidelines were developed for estimating incidental catch TACs for depleted Tier 1 species in need of rebuilding. These first recommended using either the companion species approach or stochastic projections of a fitted stock assessment model, using recent known catches, to determine the minimum level of catch that could be considered to be incidental within a mixed fishery.

For the companion species approach to be valid for a given species it would be best to first test that the repeatability of species composition at the scale of strata to be used in the analysis really does occur. This would be especially important for those species which are not Tier 1 species or are less often targeted as being only relatively low value species. The assumption that industry are able to predict, approximately, the species composition that will occur in relatively fine strata around the coast is a very strong assumption underlying the companion species method so testing it before applying it would strengthen the defensibility of its results.

An advantage of using stochastic projections of fitted Tier 1 assessments is that they can generate an array of incidental-catch options involving levels of catch relative to the time predicted to recover. An improvement over the use of deterministic projections, as used previously with School Sharks, is that the relative likelihood of recovery can also be approached.

An important aspect of setting an incidental-catch TAC that needs more emphasis is the avoidance of increased discarding. There remains a danger of setting such a TAC too low leading to difficulties in obtaining sufficient quota to land truly incidental catches and hence leading to increased discarding. Once an incidental-catch TAC has been agreed upon then the guidelines recommend three additional steps for rebuilding species. These could be implemented in any order.

The first additional action would be to explore the range of possibilities for the rebuilding species by using stochastic projections of the latest fitted assessment model similar to those that can be used to set an incidental-catch TAC but including plausible alternative scenarios of recruitment and mortality. The aim of such stochastic projections would be to examine the possible outcomes of the rebuilding strategy, which might include the possibility that the species concerned may either never rebuild or at least take much longer to rebuild than deterministic theory might recognize. The value of such a procedure is that managers and industry would then be more informed about what might actually happen in reality rather than just in theory.

The second additional action would be to regularly test for continued successful avoidance of rebuilding species by industry using automated analytical routines applied to available log-book and quota-holdings data-bases. This would be required because except where conditions-of-operating proscribe the capture or landing of a species there is nothing in the quota management system that precludes an operator from accumulating quota, even incidental-catch-only quota, and then targeting a species. The aim of checking for continued successful avoidance would be to ensure this does not occur.

The third additional action would be to have the respective resource assessment group decide whether or not the data being collected routinely for the species concerned was still considered to be representative or not. If not then expending resources in this manner should be stopped. Without some explicit and particular design, the routine collection of data from a rebuilding species which is being successfully avoided is unlikely to generate representative data. If such data is unrepresentative then it will be of no use in determining whether or not the species concerned is actually rebuilding. It would be more constructive to use resource to gather meaningful data than to continue collecting meaningless data.

If data-poor fisheries have known reference points then it would still be possible to determine whether they were depleted to a point where they would require rebuilding. However, it is recognized that, for example, confidence in the current Tier 4 analyses is lower than with the Tier 1 analyses, which, unlike the Tier 4 analyses, consider the underlying dynamics of the stock. Either the companion species method or the use of a model assisted data-poor assessment method with projections could be used to set an incidental-catch TAC. In such cases, it would be important to monitor the success, or otherwise, at avoidance (the second additional actions recommended in the guidelines) to help determine whether there was a mismatch between the decided incidental-catch TAC and the actual catches. The absence of policy decisions on how to deal with truly data-poor species that are more normally by-catch or occasionally by-product species makes further recommendations with respect to relatively data-poor species difficult, This issue could be re-visited once more detailed policy and guidelines are decided with respect to data-poor species.

Application of the methods discussed here to TEP species is, of course, possible, but currently there is no acceptable level of capture for TEP species and so the applicability of, for example, stochastic projections of a population dynamics model, would be restricted to examining the implications and risks associated with mortality events or mortality rates known to be occurring.

Much of the material in this report has already been presented or used in resource assessment group meetings since 2011 when the project began. The companion species approach has been used to set incidental-catch TACs for eastern Gemfish and Blue Warehou, while deterministic projections have been used to aid in setting incidental-catch TACs for School Shark. This report recommends modifying both these approaches (testing the assumptions behind the companion species approach before its application, and using stochastic projections rather than deterministic projections.

The algorithms developed to examine the success at avoidance of rebuilding species have already been used and reported to the RAGs for both Blue Warehou and School Sharks.

Currently, the ISMP continues to collect data routinely with respect to rebuilding species, this part of the report has not yet been presented to the RAGs but will be this year.

It is recommended that the guidelines for handling the assessment and monitoring of rebuilding species being considered and adopted by SESSF RAG and then implemented in the RAGs which have rebuilding species (Shelf RAG and Shark RAG).

1.1.1 Keywords

Eastern Gemfish, School Shark, Blue Warehou, rebuilding, incidental catches, by-catch TAC, by-catch, by-product, avoidance, companion species, risk assessment.

2 Acknowledgments

We would like to thank the rest of the SESSF assessment team at CSIRO: Jemery Day, Sally Wayte, Robin Thomson, Rich Little, and Judy Upston for discussion of these subjects. In addition, the members of the different SESSF RAGs have generated and joined in discussion of these subjects and added real value to our analyses. The RAGs constitute a forum in which such ideas can get a close review and that has been appreciated in the development of the work reported in this report.

3 Objectives

Four objectives were envisaged when this project was established:

4. Develop guidelines and tests to determine if incidental catch levels for any species are likely to be unsustainable or contrary to the principles of the Harvest Strategy Policy, with particular reference to species under rebuilding strategies and provide case examples.

5. Conduct risk assessments to determine acceptable levels of incidental catch TACs for species under rebuilding strategies within the parameters of the Harvest Strategy Policy.

6. Determine whether any of the methods developed under objectives 1 and 2 can apply to relatively data poor species; develop guidelines for application to species for which there is only catch data.

7. Assess the feasibility of extending the methodology above in objective 1 to develop a practical and workable methodology to estimate acceptable capture limits for rare and TEP species.

Given that there exists legislation (the Environment Protection and Biodiversity Conservation Act of 1999; EPBC Act) for dealing with threatened, endangered, and protected species, the last objective was only considered briefly from an analytical methods point of view.

4 Background

4.1 Introduction

Incidental catches are catches of species taken while fishing for or even specifically targeting other species. Species that are caught only incidentally can be non-targeted for an array of reasons but generally it is because they are of limited or no commercial value (so-called by-catch species) or because regulations require them not to be targeted. Those species which are of limited value can be referred to as by-product species. These are not the aim of the fishing but they can add some value to the landed catch. However, those species which, as an outcome of either regulation or legislation, are not to be targeted are the group which the work in this report is focused upon; although the sections relating to data-poor species are also related to classical low or no commercial value by-product and by-catch species.

The current Commonwealth harvest strategy policy (HSP) for targeted species requires that should the median estimate of the spawning stock biomass of a species fall below its defined limit reference point (LRP) then there should be no further targeted fishing, at least until after the stock had rebuilt to above the LRP. The LRP is set at $\geq 0.5B_{MSY}$ or a proxy, and the proxy used, in almost all cases where biomass estimates are possible, has been defined as $20\%B_0$, where B_0 is defined as the equilibrium unfished spawning biomass (DAFF, 2007; Rayns, 2007). Species that fall below the LRP within the Southern and Eastern Scalefish and Shark Fishery (SESSF) include eastern Gemfish (*Rexea* *solandri*), School Sharks (*Galerius galeus*), Blue Warehou (*Seriolella brama*), and very recently Redfish (*Centroberyx affinis*).

A great deal has been written about the different meanings that can be attributed to the terms 'by-catch', 'by-product', 'targeting', and other terms (see **Table 1**). Most such discussions arise because implicit in the notion of targeting is some measure of 'intent to catch' and determining whether there was intent when a species is reported as caught is effectively impossible to demonstrate unequivocally. With respect to those species that are under a rebuilding strategy and are required to be avoided, essentially the best that can be achieved when using fisheries log-book data is to determine whether avoidance was successful or not successful.

This current work is about the management of species taken as incidental catches and, in line with the objectives, will be considering details relating to rebuilding strategies, the utility of the companion species approach to setting non-target TACs, the avoidance of rebuilding species, how best to conduct risk assessments for such species, and whether any of the insights developed with respect to non-target species can be applied to data-poor and TEP species.

Table 1. Terms used in discussions of targeting within fisheries. Selected and modified from Alverson et al. (1994); the United States Magnuson-Stevens Fishery Conservation and Management Act, and DAFF (2007).

Term	Definition
Target catch	Species that the fisher intended to catch, prior to setting fishing gear.
Key Commercial Species	A species that is, or has been, specifically targeted and is, or has been, a significant component of a fishery.
Targeting	Fishing selectively for particular species or sizes of fish; implies an intent to catch a particular species.
Non-target catch or by-product	Any part of the catch that is kept or sold by the fisher but is not the target species.
By-catch	Species taken incidentally in a fishery where other species are the target, and which are always discarded.
Primary species	The species being considered when setting an individual species TAC.
Companion species	Species that should also be considered when setting the TAC of the primary species, because a considerable proportion of the primary species catch is taken with the companion species as non-target catch.
Associated species	Species that may also be considered when setting the TAC of the primary species, but are of less importance in terms of primary species catch than companion species.
Discards	Species that are not marketable, and are caught but not retained.

4.2 Companion Species

There is a trade-off between setting an incidental catch TAC at a level that permits operators to land commercially valuable fish caught incidentally, and thereby avoiding undesirable and unreported fishing mortality, and setting the TAC too high so that fishing mortality remains too high to allow rebuilding, even though catches may be reduced from historical levels. Currently the management of species that have been depleted below the harvest strategy policy (HSP) limit reference point of 20%B_0 relies on setting a non-target TAC and, importantly, on the agreement and cooperation of the fishers involved to abide by the intention of the management. This approach has experienced some problems and for species such as Blue Warehou, eastern Gemfish, and School Sharks, (and most recently redfish – *Centroberyx affinis*) it remains unknown whether setting a TAC for incidental catches is working as a recovery strategy. It remains unknown because for none of the three main species listed has there been any major evidential support for a significant recovery. It is just an assumption that reducing catches to the lowest level achievable in a mixed fishery will always lead to stock recovery. Whatever the case, there are also issues in determining whether such incidental-catch only species are recovering (see later discussion).

A key problem in any rebuilding strategy is deciding what would be an appropriate level of catch for depleted species if they are only to be taken as incidental catches with other species in a mixed fishery. Generally, in the course of stock assessment analyses and related management advice, when TACs are set on an individual species basis, catches of other species, even in a mixed fishery, are not considered. In multi-species fisheries, such as the SESSF, there can often be technological interactions between species where fishing effort directed towards one quota species will normally result in a mixed catch of fish that may include other quota species. Fishers can sometimes improve 'targeting' to some degree through fishing different areas and depths, seasons, times of day and by modifying gear. But catches remain mixed and this is a problem when attempting to minimize fishing mortality of rebuilding species.

An intuitively attractive option is to be explicit about the multi-species nature of the catches and use the observed catches of different species when they are caught together to derive an estimate of what amount of a particular species would be predicted to be taken unavoidably when fishing for other non-depleted species. This approach has been developed through time with minor improvements being included in different iterations, and has been termed the Companion Species approach (Tilzey, 1994; Klaer and Tilzey, 1994; Klaer and Smith, 2008, 2012).

4.3 Rebuilding Strategies

In the Commonwealth jurisdiction, fishery specific harvest strategies with their particular harvest control rules are selected from the array available and put in place to meet the intent of the harvest strategy policy (HSP). The HSP requires the Australian Fisheries Management Authority (AFMA) to implement a rebuilding strategy for stocks assessed to be below a defined limit reference point ($B_{LIM} \geq 0.5 B_{MSY}$, or its proxy 20%B_0). The purpose of rebuilding strategies is to increase stocks to above the limit reference point within a reasonable timeframe. In fact, the explicit intention is to rebuild them to the target reference point but the HSP can be interpreted to imply that once above the B_{LIM} the normal application of the harvest control rule that is part of the harvest strategy for non-depleted species will be sufficient to achieve rebuilding to the target reference point:

> "For a stock below B_{LIM}, a stock rebuilding strategy will be developed to rebuild the stock to B_{TARG}. Once such a stock is above B_{LIM} it may be appropriate for targeted fishing to re-commence in-line with the stock rebuilding strategy and harvest strategy." (DAFF, 2007, p4).

The phrase “may be appropriate” can be interpreted as suggesting there is, or needs to be, an alternative to applying the usual harvest control rules for a species when its status is between the limit and target reference points. The requirements of rebuilding strategies can thus be considered to be somewhat confusing and ambiguous. This is confusing because no guidance is given on when it might not be appropriate to apply the usual management controls within the Harvest Policy Framework. The ambiguity also relates to the notion of a reasonable time frame. There is some indication that "reasonable" relates to being within one to three times the generation time for a given species concerned, although ‘generation time’ is not defined in the HSP. At least part of the ambiguity exists because if the management of a species comes to the attention of the EPBC Act then returning a species back to its usual (i.e. non-depleted) harvest strategy will include extra processes, which may lead to delays. Such details require the HSP to retain some flexibility with its application.

Setting a Total Allowable Catch (TAC) of zero is one, seemingly obvious option to achieve rebuilding, and this is, in fact, a plausible option for easily targeted species such as orange roughy (*Hoplostethus atlanticus*), although even with orange roughy there can be a significant by-catch of oreo dories and *vice versa*. However, for multi-species fisheries, such as generally occurs within the rest of the SESSF, a catch of zero can be difficult to achieve as species may be unintentionally (incidentally) caught when operators are legally targeting species with which the depleted species tends to be associated (this association is the basis of the companion species analyses). To prevent the wastage of these incidental catches, ‘by-product’, ‘by-catch’, or ‘non-targeted” TACs are set, generally using the TACs of the healthy stocks of associated species as a guide to what would be an unavoidable level of catch (the ‘companion species’ approach has been used for Blue Warehou and eastern Gemfish). By-catch or by-product TACs must be set that allow the stock to rebuild within the timeframes of the explicit rebuilding strategy.

The intention is to set the by-catch TAC at a level that will minimize fishing mortality and allow the affected stocks to rebuild naturally whilst still permitting a fishery for the non-depleted associated species found in the same areas. If a fisher catches a species for which they cannot obtain quota they are forced to discard the catch and it is generally assumed that all discards will be dead, which is likely true for all commercially significant species.

Discarded fish are particularly problematical within a rebuilding fishery because they constitute potentially unaccounted fishing mortality. This is a problem because if the by-catch TAC is set at a level below the true unavoidable catch there will be insufficient quota available to allow fishers to retain what fish they do catch fish and some will be forced to discard. A further problem with discarding is that while estimates of discard rates can be made from Integrated Scientific Monitoring Program data (ISMP), these estimates are often very uncertain. This is especially the case for species for which catches are low or uncommon. The catches of rebuilding species generally ought to be low or uncommon, so the true level of discarding of such species is often poorly known. Importantly, low TACs can have the appearance of being conservative but in fact, if they are set too low, they could lead to significant discarding and then the actual fishing mortality may in fact remain too high for rebuilding. Thus, although many stakeholders may believe the management is appropriately conservative, the original intention of rebuilding will fail.

4.4 Avoidance of Rebuilding Species

4.4.1 Introduction

In the Commonwealth Harvest Strategy Policy (HSP; DAFF, 2007), if a fished stock is assessed as being below a limit reference point then targeted fishing for that species is supposed to cease. Nevertheless, such fisheries remain under quota management and so a Total Allowable Catch (TAC) is set each year but that TAC is only intended to be used to allow any unavoidable by-catch to be landed legally. The phrase ‘unavoidable by-catch’, intends to emphasize that catches of such depleted species should generally be avoided but that when fishing for other species in a mixed species fishery such captures can be expected to occur.

In addition to the problem of deciding on an incidental-catch TAC, there is a potential problem that even if an incidental-catch TAC was set at exactly the correct amount it relies on all fishers avoided them appropriately. The structure and operation of the current quota management system has led to the expression of some unintended consequences for incidental-catch-only fisheries on depleted stocks. Within the quota system, fishers can lease in amounts of quota at or before the start of a fishing season when they are planning their operations for the year. Thus, it is possible for operators to collect together sufficient amounts of quota for them to consistently target a particular species for which they may have markets arranged. The problem with this is that it would be perfectly legal for one or a few individuals to accumulate sufficient quota units, out of the available non-target-TAC, to go out and target the assumed incidental-catch-only species. If this did occur it would have the doubly negative effect of first increasing catches above true incidental catch levels, and secondly, it would also reduce the amount of non-target-TAC available to other fishers which may again lead to increased discarding and therefore increasing the fishing mortality imposed to even greater levels.

With current regulations it is not illegal to accumulate quota for any species (even non-target species) and then target them. Such behaviour is against the intention of the management and the Harvest Strategy Policy but presently this would not be illegal behaviour. It needs emphasis that, under current regulations, as long as operators have sufficient quota available to cover the catches they take there would be nothing illegal about a fisher targeting a supposedly ‘non-target’ rebuilding species. There are no mechanisms currently in the quota market to rationalize the usage of quota for rebuilding species to bring it into line with the HSP’s intent. However, it is possible to introduce conditions on fishing operations that can assist in controlling the levels of incidental-catch of rebuilding species. These conditions can include daily catch limits, trip limits, and even specific maximum ratios of incidental-catch species to target species (examples of these are in place for School Shark (see Appendix in section 12, p100).

4.4.2 Failure to Avoid Rebuilding Species

Following the introduction of formal rebuilding strategies and the avoidance of depleted species such as Blue Warehou, eastern Gemfish, and School Shark, a number of years passed during which the log-book records of some operators gave the appearance that they were not adhering to the intent of the HSP and rather than avoiding rebuilding species were taking some opportunities to target them. To examine this situation in detail a means was required of identifying or classifying when such behaviour was occurring (Haddon, 2011b; Haddon, 2012). However, the occurrence of a high catch in a single shot does not imply that the operator involved was deliberately targeting a particular species. The three main rebuilding species that are components of a diverse mixed fishery, Blue Warehou, School Shark, and eastern Gemfish, are all species which can have patchy or schooling distributions both through the year and geographically so that large catches can certainly occur unintentionally. Criteria other than just the size of any particular catch of a rebuilding species were required.

This section examines the characteristics of a fishery as it transitions from a targeted fishery to become a non-targeted fishery. It describes the development of a standard algorithm for processing fisheries log-book data to identify fishing patterns indicative of a failure to avoid a particular species. The currently depleted species, School Shark (*Galeorhinus galeus*), will be used as a case study for such analyses. This species is taken as incidental by-catch in the Gummy Shark fishery (*Mustelus antarcticus*), one of the largest and most valuable fisheries within the SESSF. The two species are routinely caught together although some areas are more prone to joint catches than others.

Avoiding School Sharks is now reported by shark fishers as hampering their attempts to catch Gummy Sharks because they are effectively excluded from some prime fishing grounds (in particular around Flinders Island). As the Gummy Shark fishery is one of the more valuable fisheries within the SESSF this issue has many implications.

In the past the issue of a small number of fishers seemingly targeting ‘non-target’ rebuilding species has caused conflict among industry members in the fisheries for School Shark, Blue Warehou, and eastern Gemfish where most fishers successfully avoid these species. Methods for its detection will be discussed and when these methods were implemented in practice, a degree of peer pressure, coordinated efforts by industry associations (especially SETFIA), and the inclusion of requirements in the annual operating conditions, appear to have reduced the practice in more recent years; although there remains a need to monitor for this behaviour to prevent its re-occurrence. With School Shark catches, taken in the Gummy Shark fishery, investigations presented to the RAG in recent years gave rise to the idea that among those operators targeting Gummy Sharks their catches of School Shark should at most only be about 20% of their Gummy Shark catches. Such determinations open the way for the introduction of regulations and conditions that encourage the intended avoidance behaviour (AFMA, 2015b; see Appendix 12, p 100, for an example involving School Sharks).

A related problem experienced with highly depleted and thus by-product-only species is that reported catches can become very low. While this is the desired effect, it also has the obvious impact of reducing the information flow about the species. It therefore becomes difficult to monitor whether the stock is declining further or recovering. In addition, almost all fishers work very hard to avoid catching rebuilding species and so, because this avoidance behaviour automatically reduces the observed catch rates for most of the fleet, if information about the fishery is only available from commercial catch and effort log books and the ISMP it becomes even more difficult to determine whether a recovery has occurred or not. Further, because discarding is currently poorly reported by fishers and observer estimates are often highly uncertain for what become rare events, it becomes doubly difficult to estimate the true level of fishing mortality as applied to such species.

4.5 Risk Assessments for Rebuilding Species

The three main species within the SESSF mixed fishery currently under rebuilding strategies include Blue Warehou, eastern Gemfish, and School Sharks (redfish has now been added; AFMA, 2015c). All three of these species appear to have been depleted to below 10% B_0 at some point and there are numerous possible mechanisms operating that may be preventing recovery of these species. These mechanisms include their productivity now being so low (again for multiple possible reasons) that even the minimal mortality imposed by the mixed fishery is sufficient to maintain the stocks at very low levels. For example, there may be some depensatory mechanisms operating such that reproductive success is reduced at low stock sizes. This is not a regime shift in productivity but is rather a requirement for the natural populations to be larger than some minimum to be viable.

Another hypothesis is that there has been a change to the productivity of the species, perhaps in response to an environmental change, which can include the relative abundance of other species, such that recruitment success is now lower than it was previously. Such a reduction in productivity would have contributed both to previously sustainable fishing levels leading to its decline and the reduced fishing levels still being sufficient to keep the stock from rebuilding. It may also be the case that the reported catches are indeed very low but that an inability to obtain quota or a lack of markets for small amounts of these depleted species leads to a relatively high level of unreported discarding. The ISMP in the SESSF cannot be expected to provide precise estimates of what become relatively rare events especially with generally < 5% coverage. If the true fishing mortality is much greater than reported catches this could also explain an apparent lack of recovery through time.

Because of the lack of informative data there is great uncertainty with respect to the status of these depleted species. They could be recovering but because the TAC is so low the fishers continue to avoid them or discard them if they do catch them, or they could be declining to still lower levels because of the imposed fishing mortality, which is currently assumed to be at a sustainable level. The relative likelihood of these scenarios needs to be examined and strategies put forward to attempt to solve this management impasse.

One approach that can be used to examine these alternative hypotheses is to conduct stochastic projections of the Tier 1 stock assessments for these depleted species but making different assumptions concerning relative recruitment success and about the reliability of reported catches and discards. Obviously, this approach is only applicable to those species for which Tier 1 assessments are available although for other species it may still be possible to use simulation studies to examine the relative potential risks of different catch levels and other management interventions.

Using model projections and simulations in this way it would become possible to determine the scale of change needed to our current understanding of either recruitment success or unreported fishing mortality for such factors to be sufficient to explain the perceived lack of recovery. Such projections are termed risk assessments (Francis, 1992; Francis and Shotton, 1997) and provide for probabilistic statements regarding the relative likelihood of different outcomes (e.g. recovery above 20%B_0 or otherwise) given different management arrangements.

4.6 Data Poor and TEP Species

4.6.1 Data-Poor Species

There are many data-poor species in Commonwealth fisheries, some with only catch and catch-rate data and some with only catch data. In the extreme, where a fishery occurs only occasionally or opportunistically, even catch data may be patchy through time (e.g. the Western Deepwater Trawl Fishery, which has not operated every year). There are now numerous data-poor assessment methodologies available. Carruthers et al. (2014), and Geromont and Butterworth (2015, 2015b) provide detailed reviews of data-poor assessment methods and a review of the literature on data-poor harvest strategies is provided by Dowling *et al*., 2015a), while guidelines for the development of data-poor harvest strategies are given in Dowling *et al*. (2015b). In addition, a different FRDC funded project 2013/202 "Options for Tier 5 approaches in the SESSF and identification of when data support for harvest strategies are inappropriate." (Haddon et al, 2015) provides an overview of some data-poor methods as applied to Australian species.

The Commonwealth harvest strategy policy is due to undergo a revision later in 2016. It seems possible that one large change will be a requirement to assess the status of potentially numerous species which currently vary between being by-product and being discarded by-catch. Many of these are relatively data-poor and not included in the quota system. However, some species such as Elephant Fish (*Callorhinchus milli*) and Saw-Sharks (*Pristiophorus cirratus* and *P. nudipinnis*), which are already assessed and are in the quota system, are generally a by-catch of the Gummy Shark fishery and are only occasionally landed and have some of the highest discard rates recorded in the ISMP (Haddon, 2015). Generally, by-catch and new by-product species are data-poor in that only catch data is routinely collected, but even good estimates of catch, even of quota species, may be compromised by changing levels of discards through time. Except for the quota species the sustainability of such data-poor species are currently examined using the Ecological Risk Assessment approach (Hobday *et al*. 2011).

4.6.2 Threatened, Endangered, and Protected Species

Despite the extensive literature concerning such concepts as Population Viability Analysis, which is a species specific method of conducting risk-assessments within conservation biology (Boyce, 1992), in Australia there is currently no such thing as an acceptable catch of threatened, endangered, and protected species (TEPS). Nevertheless, it is possible to consider whether the information obtained from observers on by-catch rates can be used as some form of performance measure of a fishery's performance at avoiding the TEP species. By-catch rates as a performance measure of TEP species stock status can be misleading (Tuck, 2011). Changes in by-catch rate can be due either to changes in capture numbers or changes in abundance. Thus, analysis of TEP by-catch rates needs to be conducted in association with monitoring effort and TEP abundance independently of the fisheries statistics (colony counts of birds can be a first indicator that incidental mortality, due to fisheries or other human activities, may be unsustainable).

5 Methods

5.1 Introduction

Objectives 1, 2 and 3 (page 12) all relate to the production of guidelines and tests for setting incidental catch limits for depleted species. If a species is not depleted below the LRP (i.e. not under a rebuilding strategy) then management advice on catch levels (Recommended Biological Catch levels; RBCs) will be generated from the harvest strategy applied to the species concerned. Each harvest strategy has three components: the data used, the fishery assessment that provides estimates of the chosen performance measures, and a harvest control rule which compares the estimated performance measures with pre-defined target and limit reference points and translates this stock status into a catch recommendation (DAFF, 2007; Haddon, 2007c; Little et al., 2011). Most control rules, recommend a zero targeted catch once the stock falls below 20%B_0 or whatever limit reference proxy has been adopted in a particular harvest strategy. This is why guidelines are required to set catch levels for species within rebuilding strategies for which standard harvest control rules generate a recommended biological catch of 0 tonnes.

5.2 Companion Species

The idea of using the commercial catch and effort log-book data to characterize the typical species combinations taken in different months in different areas, in different depths, and at different times of day, and using it to estimate the expected level of catch of one species when catching a different species, has been under development since 1994 (Klaer and Tilzey, 1994). This approach has been further developed through time (Klaer and Smith, 2008, 2012). In a quota system if discarding is to be avoided or minimized then fishers need to balance their catches of different species with whatever quota allocations they have across those species. Ideally each fisher's quota mix should match their expected catches perfectly, although where this does not happen the ability to lease extra quota for some species within the quota system should allow fishers to get their balance correct. The undesirable alternative is to discard catches for which no quota is available. This is undesirable for multiple reasons including the waste of potentially valuable resources and the potential for increasing fishing mortality beyond that which is recorded and known.

If each particular species could be successfully targeted this would make balancing catches against quota simpler. However, if a large proportion of a species' catches are taken incidentally when other quota species are targeted, then maintaining the balance between quota available to a fisher and their catches becomes more difficult. This becomes especially important if the quota available for a single species declines while that for the species it tends to be caught with remains stable. Companion species were defined as species combinations that should be considered together as a group when setting fishery total allowable catches.

Many terms are used when discussing targeting, by-catch, by-product, and discards in fisheries (e.g. Alverson et al. 1994; the United States Magnuson-Stevens Fishery Conservation and Management Act, DAFF, 2007; **Table 1**). The notion of 'targeting' as usually defined implies an intent to catch a particular species but whether this can validly be applied to mixed species has often been debated in stock assessment meetings. Catches of different species can nevertheless still be categorized as targeted or otherwise by developing rules that explicitly define 'targeted', although this runs the risk of upsetting some stakeholders because of the implication behind the term 'targeted' of some explicit 'intent to catch', which may or may not have been present.

The field of fisheries has many terms which can have multiple uses and meaning ascribed to them (Haddon, 2011) and the term 'targeting' is one such term. Of course any term can be defined and given an explicit meaning, which does not always coincide with the less explicit but sometimes more common intuitive understanding. For example, Ackley and Heifetz (2001, p24) stated, when dealing with a mixed fishery in Alaska: "A problem in examining data from the fishery is that more than one species may be a target during a particular time period". Some rules can be extremely specific, thus Stergiou *et al*. (2003) working on a trawl fishery in the Mediterranean proposed: "… target species at a particular fishing ground can be objectively defined as the species contributing a percentage of Bray-Curtis similarity equal to that at which the different fishing operations form only one group in terms of both landings per day and value per day." While this is an example of a very specific and quantifiable definition it certainly does not match the more usual and intuitive definition commonly used by fishers; it is presented here merely as an example of an extreme definition. However, Stergiou *et al*'s (2003) definition should not be taken out of context and was proposed for a very specific purpose.

Intent within the notion of 'targeting' can only ever be suggested rather than demonstrated within a mixed fishery. Within the companion species approach the rule used to define 'targeting' was developed or suggested by Klaer and Tilzey (1994) who were working on the SESSF. That rule assumes that fishers target according to the relative value of the species in the catch rather than their relative weight, and that targeting, even for mixed catches, is informed by prior knowledge of where and when certain species may be caught (Klaer and Smith, 2012). As with any definition it can be accepted or rejected but an advantage of the companion species definition is that aspects of it can be tested.

The assumption of prior knowledge of where and when particular species within a mixed fishery may be caught (Klaer and Smith, 2012) is open to being tested by examining the repeatability of the occurrence of particular species and combinations of species in particular spatial and temporal strata. Thus, to use areas akin to those used in the companion species approach, it is possible to examine log-book data at 0.5° and 50m depth strata for the details of the species composition at different times to determine their relative consistency, which is the basis of the companion species analysis.

The SESSF catch and effort log-books now provide a record for each fishing operation with information, if it is complete, about such variables as date, location (latitude and longitude), time of day, measures of effort (duration of tow, length of net, number of hooks), average depth and the catch by quota species; other species are also recorded although discarded species and amounts are often not recorded or only recorded incompletely. It is this log-book data that is used in the companion species analysis. Generally the retained catch weight is only estimated, however, comparisons with the measured weight of fish landed at the end of each fishing trip indicate that these estimates are usually accurate within around ±10% of actual landings, and this also applies when the catches of the whole fleet are combined. The companion species analysis is applied to the log-book estimated catch weights rather than the landed weights.

The log-book data often contain exceptional or erroneous records with either missing data or implausible values for some variables. Hence standard rules need to be developed aimed at excluding those records not containing particular details, or that have values that are clear outliers for the typical ranges in particular fields (e.g. shallow water species being taken from waters from 1000 – 3000 metres can be rejected). After such filtering, it is not unusual to remove between 4 – 17 % or records in any given year (Klaer and Smith, 2012).

The log-books now include a field that allows the target species to be nominated by fishers but this is only ever poorly recorded (e.g. the most abundant species in the catch is often reported as the target), so a repeatable method of estimating a target species was developed. The rule was originally developed by Klaer and Tilzey (1994) and relies on an analysis of the species composition of catches, and their respective dollar values, taken in particular defined areas in particular depths at particular months of each year and at particular times of day.

5.2.1 Definition of 'Target Species'

The target species in a particular shot is deemed to be the species with the greatest portion of the total catch value in a given stratum, where the stratum is defined as a particular 0.5° section of a 50 m depth range within a given month, during the same time of the day (**Figure 1**); note the emphasis on financial value rather than relative abundance in the shot. This is a very specific definition of 'targeting' and has led to some objections in formal assessment group meetings by fishers who object to their fishing being classed as targeted. But this definition need not be taken to imply a conscious intent to catch a particular species but rather it is an indication that there was a failure of avoidance. Such a clarification might save a great deal of angst in such RAG meetings.

To allow for changes in such 'targeting' behaviour through time, each month was treated separately, which required an independent analysis of individual years (Klaer and Smith, 2012). Time-of-day was assigned according to the local time of the start and end of each shot, with each being assigned as entirely during the day, mixed day and night, entirely at night, or unknown. If the time-of-day was unknown it was given the mean value for all other shots in the given year – month – 50m_depth – 0.5° stratum (**Figure 1**).

The reported catch weight of each quota species, and the combined catch of 'other' species were then multiplied by their average landed values to produce total catch value per species in each year-month-site-time_of_day stratum. Klaer and Smith (2012) used a volume-weighted average price for each quota species from the Sydney and Melbourne fish markets between 1996 – 2002 to estimate the targeted species. The species contributing the greatest value overall was then assigned as the target species for that year-month-site, and that target was assigned back to each individual shot. This approach obviously also relies on the relative values of the different species retaining the same ranking through time. If their relative values altered or the relative order of species' values changed then this would need to be accounted for when estimating the average value per kg.

Detailed methods for the companion species approach to setting recommended biological catches for rebuilding species are provided in Klaer and Tilzey (1994) and Klaer and Smith (2008, 2012). In essence, the amount of catch of a given species taken in the SESSF within each year, which was not classified as 'targeted', is used as an estimate of the incidental catch. This approach has now been used to provide the basis for setting the TAC for Blue Warehou and eastern Gemfish. However, the companion species approach has, so far, only been developed for trawl fisheries. Thus, an alternative was required to set the TAC for School Sharks, and the method used an analysis of deterministic projections of the Tier 1 School Shark assessment model (Thomson, 2013) to determine sustainable levels of catch that would still allow for rebuilding within designated time periods.

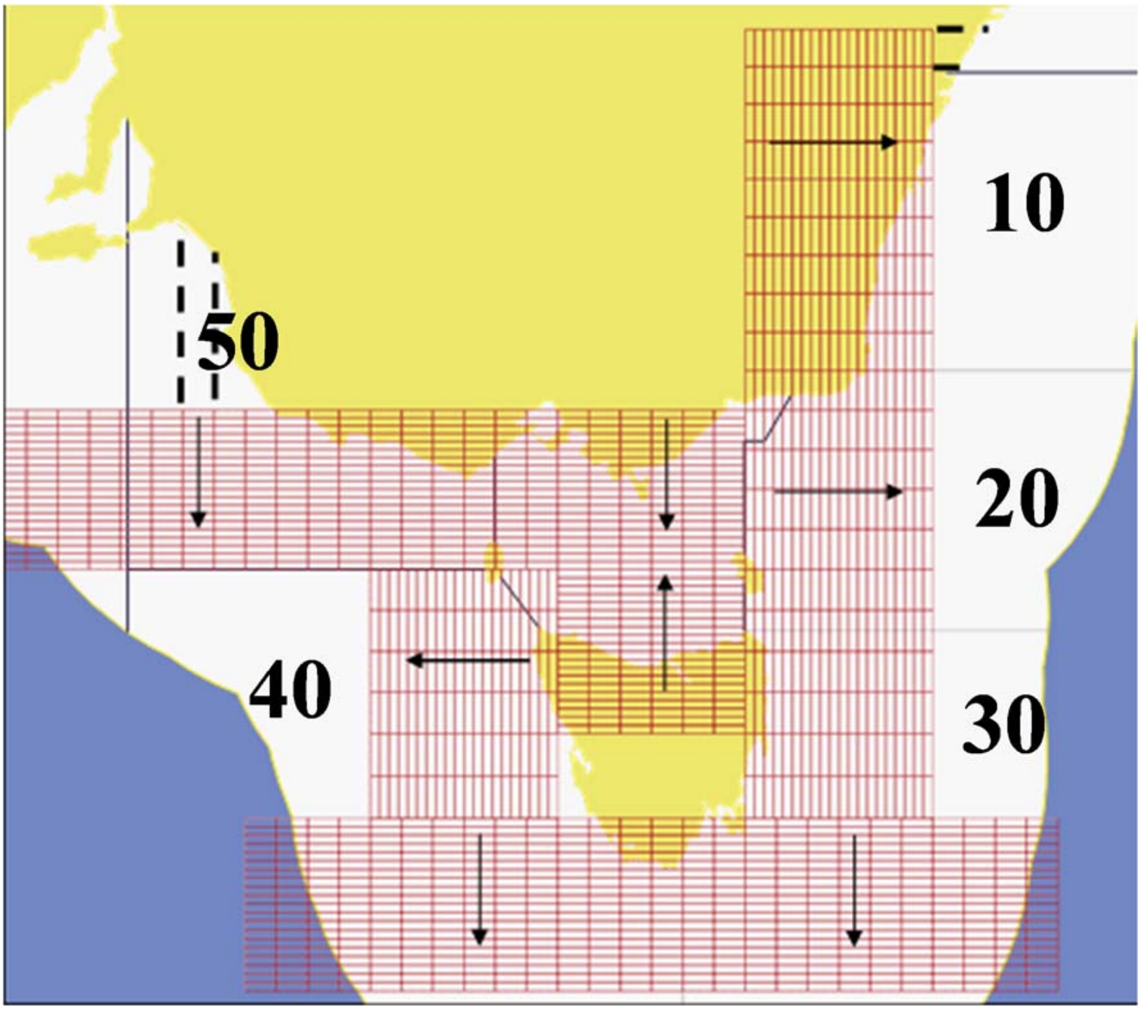

Figure 1. The subdivision of the SESSF region into 0.5° strips for target species assignment. Each half degree step along the coast is divided in the direction of the arrows (away from the coast) by 50 m depth intervals. The spread of strata across the GAB is truncated for clarity, with the grid artificially shifted away or across the coast for ease of representation (after Klaer and Smith, 2008). The larger numbers relate to the SESSF catch and effort reporting zones.

5.2.2 Strengths and Weaknesses of the Companion Species Approach

The intent of a rebuilding strategy is to restrict catches to only those that would occur when a species is never specifically targeted but nevertheless will be taken incidentally when fishing for other species. The companion species approach relies upon identifying those catches which are not-targeted (as specifically defined previously) and summing those while ignoring those which are deemed to have been targeted (where targeting is defined above as being determined by the relative value within the catch of each shot). There are both advantages and disadvantages to the Companion species approach (**Table 2**). However, it should be remembered that it is often simpler to criticize any method than it is to develop an alternative.

Table 2. Some of the advantages and disadvantages of the Companion Species approach to estimating incidental catch levels for by-catch-only species.

Advantages	**Comment**
It works	The method can be relied upon to provide an estimate of the incidental catches for a species which is repeatable and defensible
Fishery-dependent	Uses the commercial catch and effort log-books, which are routinely collected. So the only extra data required is the average prices.
Relatively simple	The approach is simple to implement once the data are available
Disadvantages	
Targeting	It is accepted that fishers do not necessarily target single species, yet the method assumes intent and predictability based on season and location.
Requires strong assumptions	It assumes fishers can develop prior knowledge of where and when particular species within a mixed fishery may be caught.
Obtaining price data	Prices vary through time and obtaining the data involves costs
Price or Profit	Market price ignores other costs involved in determining the value of a catch.
It does not reflect underlying population dynamics	The estimated incidental catch may still be too high to allow for rebuilding, or may be more conservative than the species requires for rebuilding. The estimates are derived without reference to the underlying population dynamics.
Uncertainty is poorly described	The variability of catches with respect to the averaging within strata and across years is not accounted for.
Missing data can affect the outcome	The data cleaning methods could be taken advantage of by less scrupulous operators providing implausible values for depth or location on those shots with large catches of a by-catch-only species.

5.2.3 Data used in Current Examples

To illustrate some of the properties of the mixed species fishery data, including the relative frequency of multiple species occurring in single records and which species are captured with which others in each year, the SESSF log-book data for the South East Trawl fishery was restricted to depths between 0 – 700m and the years 1998 – 2013 were used. This entailed a consideration of the records for 21 different species (**Table 3**), although two were predominantly GAB species (Deepwater Flathead and Bight Redfish) and were omitted from some analyses.

Of particular interest was how often 1, 2, 3, or more species were reported together in single records, and the extent of changes through time of the typical species composition in trawls. Data for 2014 were available but fishing in 2014 appeared atypical for a number of reasons (for example, the TAC for more species than usual was not fully caught) and the data from that year appears to be very different to earlier data. These unusual events are interesting in their own right but would only confuse the illustration of changes through time, so the 2014 data were omitted in case they introduced more heterogeneity in species composition by strata than was usual.

In addition, to test the assumption that it is possible to develop prior knowledge of where and when to catch particular species, 0.5° x 0.5° cells containing large numbers of records were identified and the seasonality (monthly occurrence) of the species composition was compared between those years with the largest number of records. The same analysis was repeated for the 50 m depth strata within the 0.5° x 0.5° cell containing the most data. Those areas with maximum data availability were then selected to maximize the chance of being able to find consistent patterns of species occurrence seasonally (by month) through different years.

Table 3. The species, sorted on total catch, used in the analyses here as found between 0 – 700 m in the South East Trawl fishery. Catch98-13 is the total reported catch over the years 1998 – 2013 and 'Records' is the total number of records.

Species	Catch98-13	Records
Blue Grenadier	82991.325	85008
Silver Warehou	32992.087	91386
Flathead	23078.696	173176
Pink Ling	12542.367	137989
Jackass Morwong	8660.228	87867
Redfish	7617.305	49667
Mirror Dory	6192.027	80338
Blue Warehou	3905.444	25414
Ocean Jacket	3824.207	61079
Ocean Perch	3073.820	77638
Royal Red Prawn (rrp)	3043.273	12266
Silver Trevally	2960.184	29853
Gemfish	2793.189	47931
John Dory	1558.515	79533
School Whiting	1529.977	13437
Saw Shark	800.817	34313
Gummy Shark	700.528	39158
Blue-Eye	693.740	16292
Deepwater Flathead	480.420	6905
School Shark	195.896	8589
Bight Redfish	4.413	15

5.3 Avoidance of Rebuilding Species

All methods in this section use the log-book data routinely collected by AFMA, which contain such fields as latitude and longitude of each shot, the catch of each quota species, and the date of fishing (giving catch, location, and season). By comparing the frequency of individual catches of a particular species per record for each quarter or year for the whole fleet and comparing that with the same distributions per vessel it is possible to identify potentially exceptional individual vessels for further consideration. The season and location of such catches can also be considered along with whether there are repeated shots physically very close to one another which caught elevated amounts of a incidental-catch-only species. Such analyses proceed to a consideration of individual records from particular vessels. This approach differs markedly from the companion species approach through only considering single species events and makes no assumptions about whether or not the presence of one species can help predict the presence of another.

Standard functions were developed in the statistical programming language ‘R’ to conduct these analyses once the data relating to particular species have been extracted from the log-book database. These functions include options to plot the catches for individual vessels in given areas and years so as to highlight whether there were exceptional events occurring consistently in association with any particular vessel. Thus catch per vessel by year was routinely plotted and compared. If any particular vessel stood out then there were functions for plotting up the geographical distribution of the catches of individual vessels and these were used to highlight the occurrence, if any existed, of multiple large catches in close proximity.

The justification for such a detailed analysis, vessel by vessel, is that if an operator was actively avoiding a species and they caught a large quantity in any particular area they should not shoot away again in the same area or close to it. Such ‘move-on’ rules are only informal but the majority of fishers exhibit such behaviour. Industry organisations, such as the South-East Trawl Fishing Industry Association (SETFIA) have actively encouraged their members to operate using move-on rules within codes-of-practice. These codes-of-practise include immediately making a report to the SETFIA base if a large catch of, for example, eastern Gemfish, were taken so that other fishers near the same area could become aware that concentrations of depleted species were nearby. Such codes-of-practice contributed greatly to reductions in the by-catch of these species, especially off the east Australian coast (e.g. Blue Warehou, Sporcic and Haddon, 2015).

Generally where a species is caught as an incidental-catch with other targeted species then their ratios in individual shots and when aggregated over different periods can be examined to identify operators with very different ratios to the majority. With respect to School Sharks, log-book data can be selected to pick out all reported catches relating to either Gummy Sharks or School Sharks or both. Attempts were made to consider the ratio of Gummy Shark catches to School Shark catches on a quarterly and monthly basis and this led to suggested guidelines that were eventually adopted (see Appendix 12, p. 100).

Any guidelines on how to implement such data searches were developed empirically with respect to the different over-depleted species. For example, with School Shark, industry members were concerned about this problem as many were having difficulty in obtaining sufficient quota to cover their incidental catches. This appears to have been less of a problem for Blue Warehou because the primary locations for that species are relatively discrete and seasonal, although fishers on the west coast (zones 40 and 50) were reporting problems avoiding them in 2011. Of course, because the analyses were dealing with the individual records of single vessels care needed to be taken to maintain confidentiality with any information made more public.

5.4 Risk Assessments for Rebuilding Species

5.4.1 Introduction

Blue Warehou (*Seriolella brama*) was used as a case study example to illustrate the use of stochastic projections of fixed catches and different recruitment levels to determine the likelihood of a rebuilding strategy be able to succeed in rebuilding a depleted stock. A rebuilding strategy for Blue Warehou was first put in place in 2008 and was revised in 2014 (AFMA, 2014). The last Tier 1 stock assessment accepted for Blue Warehou was also in 2008 (Punt, 2009); it was this assessment that was updated.

5.4.2 Analytical Methods

For Blue Warehou the Punt (2009) model for the west coast of Tasmania and off Portland (SESSF zones 40 – 50) was updated to match the requirements of the latest version of the current stock assessment software used; SS3 3.24u (Method and Wetzel, 2013). The latest total annual catches (landings plus discards) and a revised CPUE series were included in the analysis (**Table 4**). The outputs from the stock assessment obtained for 1986 – 2008 using this updated model closely matched that produced by Punt (2009). The analyses here entailed fitting the model to all data from 1986 – 2008 and then projecting it forward to 2014 under different conditions. Only the western stock of Blue Warehou was considered as it is made up of one trawl fleet and is thus simpler to manipulate and to understand.

Additional catch rate, length-composition and age-composition data were not considered or estimated after 2008 as, following its declaration as a depleted and rebuilding species, catches of Blue Warehou dropped dramatically and it became doubtful whether the CPUE data in the log-books reflected the relative abundance of the stock, or that the age- and length-composition data were representative of the stock, even if they were representative of the catches. In this way it is the dynamics of the stock as estimated by the assessment based on the earlier data that is being projected forward. By altering the recruitment levels those dynamics are being changed, by altering the catches the dynamics remain the same.

5.4.3 Scenarios Considered

The base case was the stock assessment conducted from 1986 – 2008 with the only changes to Punt (2009) being to update the format of the command and data files to match the requirements of the latest version of SS3. These new data included the latest accepted catch history for Blue Warehou (**Table 4**), which increased catches in some years (Haddon 2014), plus a revised CPUE series that enabled the previously omitted CPUE index for 1989 to be included in the assessment. The western stock was on the threshold of being over-fished in 2008 (i.e. over-fished means spawning biomass < 20%B_0) and catches in the west continued at higher levels than the east. However, neither in the east nor the west are Blue Warehou currently reported by industry as being difficult to avoid.

Table 4. The total catches (including discard estimates), estimated standardized catch rates, and TAC from 1986 – 2013 for Blue Warehou (*Seriolella brama*). TACs were introduced in 1992, although at that time non-trawl catches were only poorly regulated. Following the large reduction in TAC for 2009 onwards the CPUE is no longer considered reliable. The total catch data are from the latest Tier 4 analysis (Haddon, 2014). In the projections catches in 2014 were assumed to be the same as in 2013.

Year	Total Catch	CPUE	TAC	Year	Total Catch	CPUE	TAC
1986	112.296	1.0000		2000	336.686	0.1039	615
1987	676.231	0.9557		2001	301.925	0.1112	308
1988	443.696	0.3946		2002	307.743	0.1473	246
1989	207.97	0.9938		2003	253.577	0.1343	250
1990	983.87	0.4348		2004	507.961	0.2503	300
1991	1710.22	0.6844		2005	557.116	0.2379	300
1992	1142.19	0.3931	2000	2006	485.206	0.1678	650
1993	782.151	0.2901	1000	2007	224.586	0.1437	313
1994	757.508	0.3178	1000	2008	372.418	0.1128	365
1995	530.469	0.2142	1000	2009	132.813		183
1996	374.455	0.1463	1000	2010	154.209		183
1997	440.183	0.2533	700	2011	135.938		133
1998	591.532	0.2323	820	2012	50.862		118
1999	530.338	0.1294	718	2013	61.387		118

For most species there are generally few data that can inform estimates of recruitment for a number of years prior to the current year because a few years need to pass for new recruits to enter the fishery and affect the dynamics of CPUE and of age- and length composition data. Thus, in the original base case (by Punt, 2009), recruitment estimates were made until 2005 rather than 2008. Once the base case was established four types of projection were made. Projections were first made assuming that projected recruitment levels from 2006 - 2014 returned to the long term unfished average, as is typically done in many assessments including the ‘breakout analyses’ currently conducted in the SESSF (Haddon, 2015d; Klaer *et al.*, 2015). Then projections were made using different, lower constant (deterministic) levels of recruitment more reflective of estimated recruitment levels for Blue Warehou from the previous 20 years. Then, projections were made assuming randomized recruitment deviates from an average that was preselected to more closely reflect recent recruitment deviates. Finally, multipliers were applied to recent catches to discover what level of reporting error would be required to cancel out any recent recovery (**Table 5**).

Table 5. The four different scenarios under consideration in the Tier 1 projections for Blue Warehou.

Scenario	Description
Base Case	A repeat of the 2008 formal assessment to generate the starting state and estimate the median depletion in 2008 for comparison with the other scenarios.
Simple Deterministic Projections	Projected recruitment estimates taken as unfished average recruitment. Single projection made. The projections were repeated for other lower constant recruitment levels more reflective of those estimated for the last 20 years.
Reduced Randomized Recruitment Projections	500 projections were made with three expected mean recruitment deviate levels: -0.2205, -0.8 A standard deviation of 0.4 was used.
Under-estimated Catches	For given levels of mean recruitment, the catches since 2008 were multiplied by different constants until the median depletion in 2014 was approximately the same as that in 2008.

5.5 Data Poor Species

5.5.1 How to Investigate Data-Poor Species

The third and fourth objective in this project relates to data-poor and Threatened, Endangered, and Protected species (TEP species):

Determine whether any of the methods developed under objectives 1 and 2 can apply to relatively data poor species; develop guidelines for application to species for which there is only catch data.

and

Assess the feasibility of extending the methodology above in objective 1 to develop a practical and workable methodology to estimate acceptable capture limits for rare and TEP species.

Whether guidelines for data-poor or TEP species can be developed that go beyond the routine application of the ecological risk assessment process (ERA) is something that will be discussed, but with respect to methods for pursuing these objectives these are greatly limited, although a consideration of particular case studies may provide insights.

6 Results

6.1 Guidelines for Relatively Data-Rich Species

The first objective was related to generating guidelines to determine the sustainability of incidental catch limits for species no longer considered for targeting:

Develop guidelines and tests to determine if incidental catch levels for any species are likely to be unsustainable or contrary to the principles of the Harvest Strategy Policy, with particular reference to species under rebuilding strategies and provide case examples.

Three approaches were pursued, although each places a somewhat different emphasis on different parts of the objective. The first approach is to codify the methodology for estimating an unavoidable level of incidental catch by examining the catches across the fleet and across species at a fine spatial scale; this has been termed the companion species methodology. The second approach is to examine, relative to the whole fleet, the catches by individual vessels (fishers) of species which have an incidental-catch-only TAC to determine the success rate of the injunction to avoid a depleted species. The third approach also relates to the second objective:

Conduct risk assessments to determine acceptable levels of incidental catch TACs for species under rebuilding strategies within the parameters of the Harvest Strategy Policy.

This entailed using the latest Tier 1 stock assessment for depleted species and projecting the dynamics forward under different catch and recruitment scenarios using both deterministic and stochastic projections to determine the likely outcomes of different circumstances. This also enables the provision of estimates of the relative likelihood of failure to achieve the requirements of the HSP. Such projections differ from the deterministic projections often made for two or three years, when conducting a Tier 1 stock assessment. In the stochastic projections, the predicted outcomes from altered (reduced) recruitment dynamics were also explored as a possible explanation for the failure to recover the depleted species; the use of stochastic projections is also new to the process as currently run in the SESSF. These can be implemented in more than one way and it would be useful to compare the different approaches and determine the most effective or efficient.

The guidelines for relatively data-rich species are straight-forward (**Figure 2**). Where a Tier 1 stock assessment and harvest strategy is in place (as has been the case for eastern Gemfish, Blue Warehou, School Shark, and now Redfish) then as long as the limit reference point is avoided the usual Tier 1 harvest control rule applies. At the same time the Integrated Scientific Monitoring Program continues to collect age- and length-composition data following the resource assessment group's (RAG) approved design so as to provide the data required by the Tier 1 assessment conducted at whatever frequency is deemed appropriate by the RAG. Changes to this process are only required if the limit reference point of 20%B_0 is breached, and is breached consistently so that the species concerned is accepted as being below the limit reference point (LRP) and is expected to stay there if a rebuilding strategy is not put in place. If such a breach occurs then a rebuilding strategy is required and a way of setting the incidental-catch-only TAC is required. The strategy usually adopted is to characterize the expected incidental catches using the companion species analytical approach (Klaer and Smith, 2012) and set the TAC accordingly. If however, the fishery involved is primarily a non-trawl fishery (such as with School Shark) then the option of using projections from a Tier 1 assessment to determine alternative potential TAC values is available; previously this has been done deterministically but it is recommended that stochastic projections be used if this is required again.

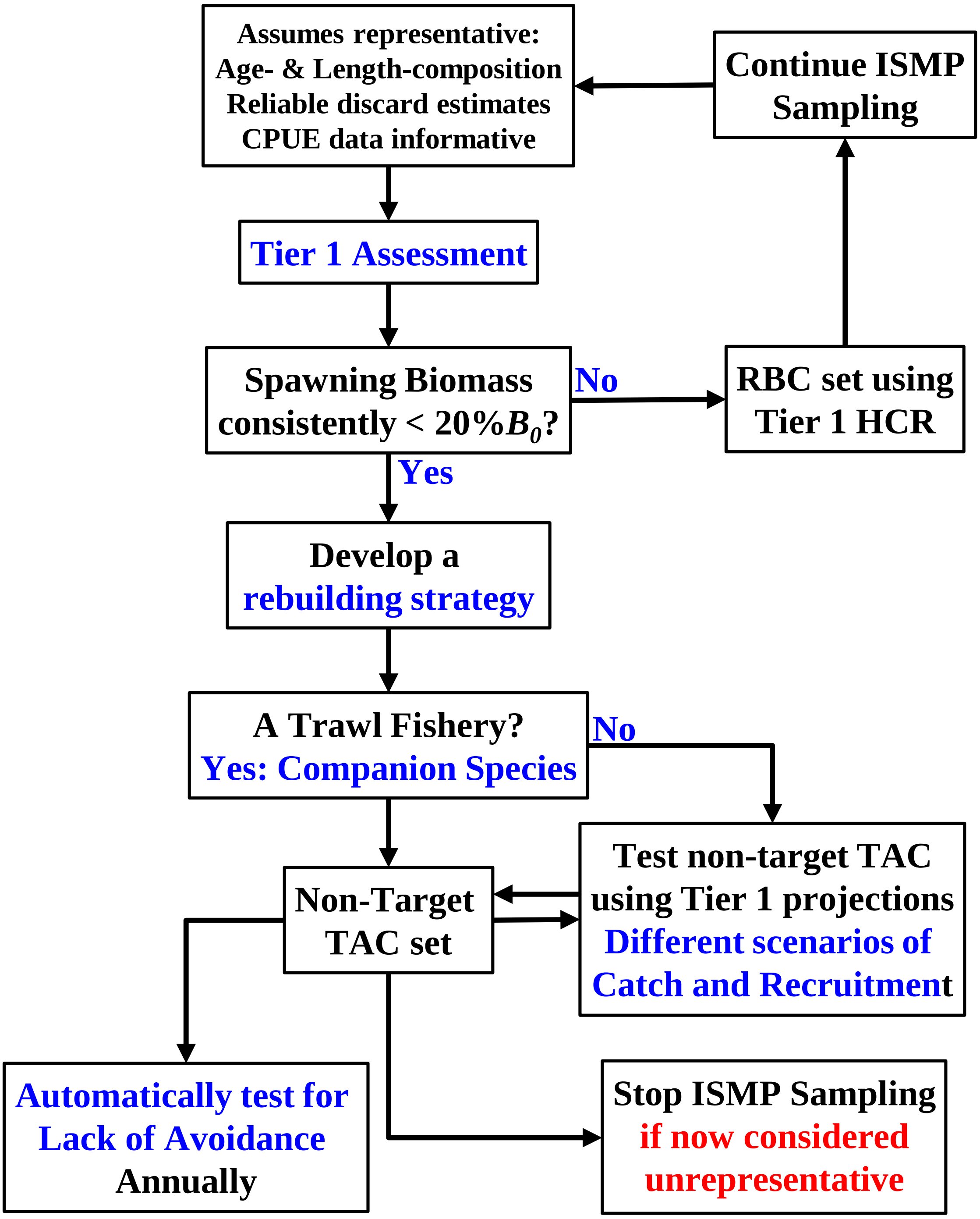

Figure 2. A flow chart depicting the steps that could be used for relatively data rich but highly depleted species.

The next steps, being made explicit here for the first time, involve two to three things (**Figure 2**), depending on the fishery and method used to set the non-Target TAC, and all of them would involve obtaining input and feedback from stakeholders.

Given the practicalities and restricted resources available within the SESSF stock assessment process the order in which the two to three subsequent steps are conducted is not pre-determined as long as each step is eventually considered and time-tabled soon after a species is determined formally to be below the Limit Reference Point.

6.1.1 Test for Successful Avoidance

The first step involves regularly testing whether or not the fleets involved in the catching of the species concerned are failing to avoid the species in any systematic manner. Given a standard (unchanging) database design it should be possible to set up automated analyses that examine catch by vessel by area by time within each year so as to highlight exceptional catches occurring more often than expected. Such analyses would have two purposes; the first being to test whether there was any evidence that some individuals were failing to make sufficient effort to avoid the depleted species; the second purpose would be to determine whether there was any evidence that the depleted stock was beginning to become more abundant and hence more difficult to avoid.

Such analyses need to be relatively wide ranging, for example, it was unexpected that there would be increasing catches and corresponding CPUE of School Sharks being taken by the trawl fleet in the SESSF. These are certainly not targeted by trawlers and, to date, these trawl data and analysis constitute the only clear evidence that some recovery may be occurring in School Sharks (Haddon, 2015). When the 2014 data are added to the trawl School Shark CPUE analysis the upward trend in CPUE since about 2007 continued, despite a minor drop in the mean estimate for 2014 (**Figure 3**).

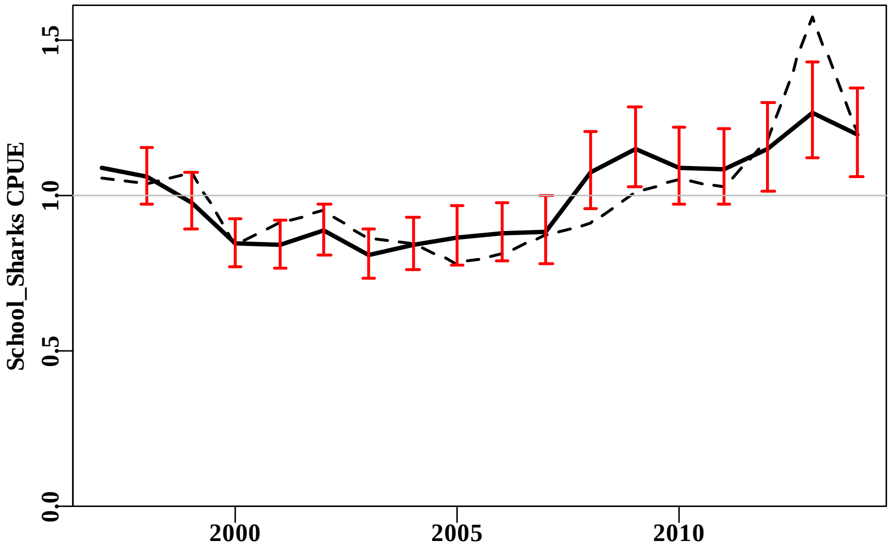

Figure 3. The standardized CPUE for School Sharks taken by trawl in SESSF zones 10 – 50, and 82 and 83 within the GAB in depths < 650m. The optimum model was LnCE = Year + Vessel + Zone + DepCat + Month. The dashed line is the trend for the annual geometric mean; with each trend scaled to a mean of 1.0.

6.1.2 Test non-Target TAC using Stochastic Projections

The second step, if the TAC wasn't set using stochastic projections, is to use the latest Tier 1 stock assessment (which is assumed to have appropriately characterized the productivity and expected dynamics of the stock) to test under what conditions the TAC, predicted by the companion species analysis, is likely to succeed and under what time-frame. Feedback from the resource assessment group, and other stakeholders where appropriate, would be required as to what scenarios to test in the forward projections; especially with respect to alternative scenarios of recruitment levels and of discard levels (catch multipliers).

The design of the scenarios should take into account the range of potential catch values that might occur and especially whether the recruitment dynamics should be varied from the average predicted recruitment. This analysis could be used to set or modify the non-target TAC from a companion species analysis if this was likely to reduce discarding or might solve some other management problem while still leading to recovery within an acceptable period. Further, if the companion species analysis was deemed difficult, perhaps through a lack of availability of recent relative prices for different species or major changes in the species composition in different areas, then the proposed Tier 1 projections, under different scenarios, could also provide an alternative means of generating a recommended RBC/TAC for depleted species.

In addition to using such stochastic projections to test the implications of incidental-catch-only TACs, stochastic projections can be used to test the implications of altered recruitment dynamics on any species even if it is not classed as overly-depleted. They can also be used to explore the expected population dynamics of TEP species if required (see later).

6.1.3 Stop Collecting non-Representative Data

The third step involves deciding whether to stop standard sampling within the ISMP for stocks under a rebuilding strategy where catches no longer provide a representative sampling of the stock. To date this has not occurred nor has it been adopted by SESSF RAG. However, if avoidance is occurring successfully, as is occurring, for example, in the Blue Warehou fishery (Sporcic and Haddon, 2015, p168), then the generic sampling conducted by the ISMP would no longer be representative of the stock in question so it would be better not to sample it in the usual fashion and instead use more resource to better sample different non-depleted species for which representative sampling is a possibility. Of course, should a particular and separately designed sampling schema be developed for one of these non-target species then applying such sampling may be a reasonable strategy. This would be the case, for example, if industry members make the effort to collect data from all such non-target species that they do catch incidentally. It is important, however, that should such sampling occur this be done with an appropriate design so that the best use of such data can be made.

It may also be possible to conduct industry based survey shots in a designed fashion, although this has not yet been implemented.

The intent of this third step is not to stop sampling altogether but aims to push focus onto the idea of collecting representative and valid samples that would be of value in assessing the stock's status rather than inadequate and patchy samples that might add more noise than information.

6.1.4 Guidelines Conclusions

Currently, when a species is deemed to be persistently depleted below the LRP then a rebuilding strategy is put in place, but any on-going monitoring appears to be conducted in a relatively *ad hoc* fashion. The guidelines for the relatively data-rich species listed here are an explicit account of what could or should be done to provide a more defensible strategy for dealing with such depleted species. The three potential actions following the estimation of a non-target TAC for a given species are 1) regularly (automatically) test for any systematic failures to avoid catching non-target species, 2) use stochastic projections of different catch and recruitment scenarios to test the likelihood of success of a rebuilding strategy, and 3) have the Resource Assessment Group provide advice on whether or not to continue regular ISMP sampling for what seems likely to become non-representative data (keeping open the option of targeted sampling to provide informative data). These combined provide a means of ensuring that a rebuilding strategy is being appropriately implemented. They only provide weak evidence that true recovery of a particular depleted stock may be occurring and some other approach will generally be required to gain stronger and more defensible evidence of recovery. Once recovery has been supported by evidence and some normal fishing has begun then generic ISMP sampling should be re-started.

6.2 Use Companion Species to set TACs

6.2.1 Introduction

Once a species has been accepted as being depleted below the Limit Reference Point (LRP) then a particular value for a non-target TAC needs to be estimated. One of the currently accepted approaches for doing this is to use a companion species analysis. However, to date, this has only ever been applied to the trawl fisheries; for example, it hasn't been applied to the School Shark fishery, which used an empirical and a deterministic model based approach to estimate what level of catch should still permit recovery. If a need arises for the use of the companion species approach in one of the non-trawl fisheries then the same general methodology could be applied but this would require minor modifications to suit it to non-trawl methods and to the geographical extent of the fishery; in effect it would need to be calibrated for a different fishery.

If the companion species approach is to be used then an important assumption that needs to be met is that the prices/value of the different species involved stays stable relative to each other through time. Data are not routinely collected to test this so an obvious recommendation is that if the companion species methodology is to continue being used then such relative price data should be collected routinely.

From the South-east Trawl Fishery, between 0 – 700m depth, out of 18 species (Flathead, Jackass Morwong, Pink Ling, Gemfish, Redfish, Silver Trevally, Blue Grenadier, Silver Warehou, John Dory, Mirror Dory, Bight Redfish, Deepwater Flathead, Ocean Jacket, Blue-Eye, Ocean Perch, Royal Red Prawn (rrp), Blue Warehou, School Whiting, School Shark, Gummy Shark, and Saw Shark) single trawl records contain up to a maximum of 14 species with most records containing between 2 – 5 species (**Figure 4**; **Table 6**).

Table 6. Number of records and proportional distribution of numbers of species per record.

Species	Records	Proportion
1	33644	0.10200
2	67159	0.20361
3	80127	0.24293
4	65042	0.19719
5	42813	0.12980
6	22824	0.06920
7	11117	0.03370
8	4589	0.01391
9	1718	0.00521
10	589	0.00179
11	167	0.00051
12	38	0.00012
13	10	0.00003
14	2	0.00001

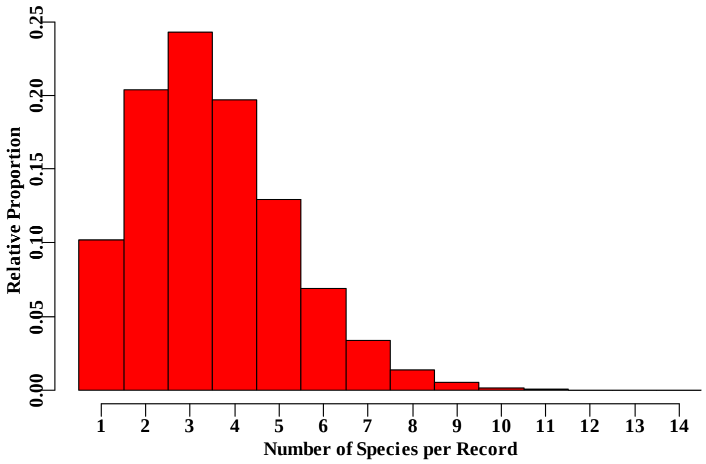

Figure 4. The relative proportion of the number of records, out of 329,839, containing between 1 and 14 species recorded, out of a possible 18 species). 97.8% of all records contain between 1 – 7 reported species.

6.2.2 Proportional Catch by Species by Year

The companion species methodology permits an analysis of individual strata by year to allow for changes in targeting and changes of the emphasis the fishery puts onto different species through time. To date, however, such changes have not been taken into account when estimating a non-target TAC even when the relative catches within the fishery change quite markedly (**Table 7**; **Figure 5**). For example, in their companion species analysis (Klaer and Smith, 2012) the volume-weighted average prices came from 1996 – 2002. There were large changes in the proportional representation of different quota species in the reported catches even between 1998 – 2002 (**Figure 5**), which would have had an influence on the volume weighting depending on the year for which the companion catches were being estimated.

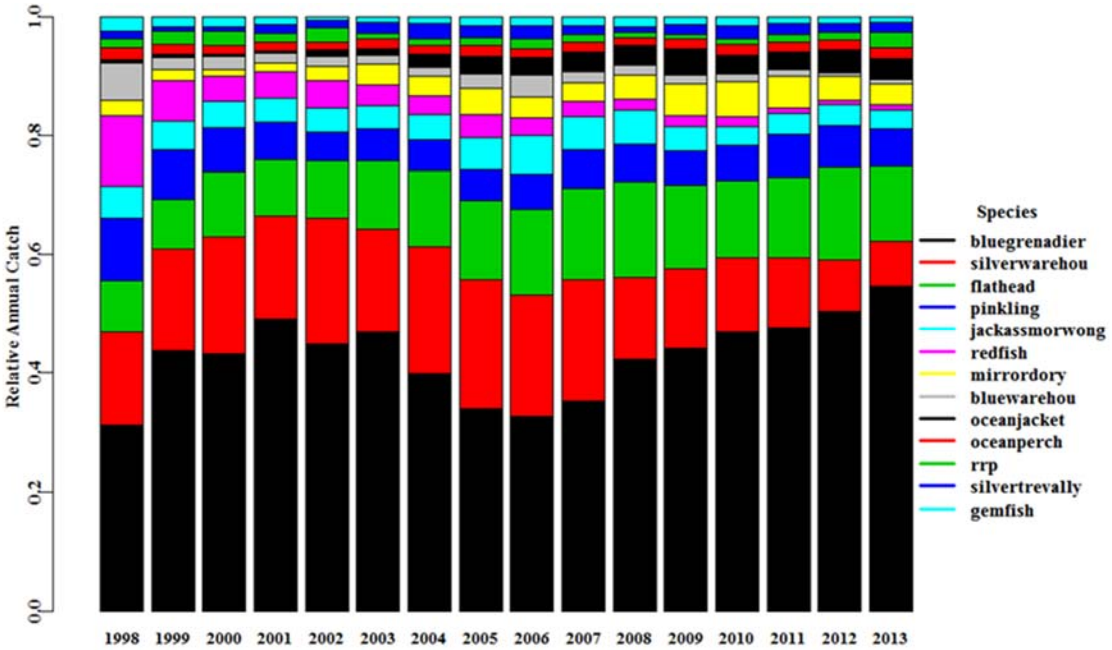

Figure 5. The relative proportion of the 13 species whose reported cumulative catch was greatest over the 1998 – 2013 period. The species Blue Grenadier to Gemfish in the legend reflect the order of the bars from bottom to top, with the total catch of Blue Grenadier being the greatest and that of Gemfish being the lowest.

The proportion of different species changes by relatively large amounts with different species exhibiting different changes. This relates to both changes in the TACs for some species, especially following the introduction of the SESSF harvest strategy policy in 2005. This change was followed by the introduction of the Commonwealth HSP in 2007, which moved the target reference point from 40%B_0 to 48%B_0, and both harvest strategies led to significant declines in catches (**Figure 6**) from 2005 onwards. The changes in the scale of the total catch mean that the proportional changes in catch do not always reflect the absolute catches. Thus, the proportion of blue grenadier increases from 2006 – 2013 but in reality catches of blue grenadier are relatively stable from 2008 (compare **Figure 5** with **Figure 6**). The reduction in both the absolute and relative amount of Silver Warehou is an example where the two correspond but, for example, the actual catch of Flathead by trawl declined from 2004 - 2007, but its proportional representation increased over the same period. The predictability of species composition for the valid application of the companion species approach is thus not present.

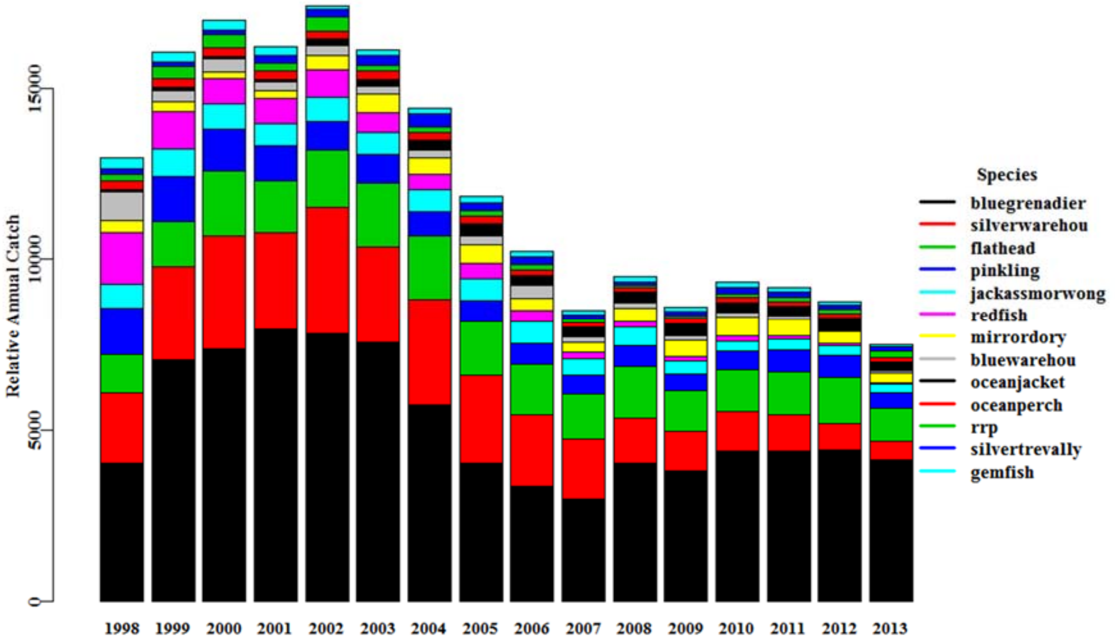

Figure 6. The relative catches (t) of the 13 species whose reported cumulative catch was greatest over the 1998 – 2013 period. The species Blue Grenadier to Gemfish in the legend reflect the order of the bars from bottom to top, with the total catch of Blue Grenadier being the greatest and that of Gemfish being the lowest.

6.2.3 Species Composition through Time

An important assumption of the companion species analysis is that different species are actually associated rather than just co-occurring by chance. By examining 0.5° x 0.5° cells in each month through time this can be tested at a courser scale than used in the companion species analysis (**Figure 7**).

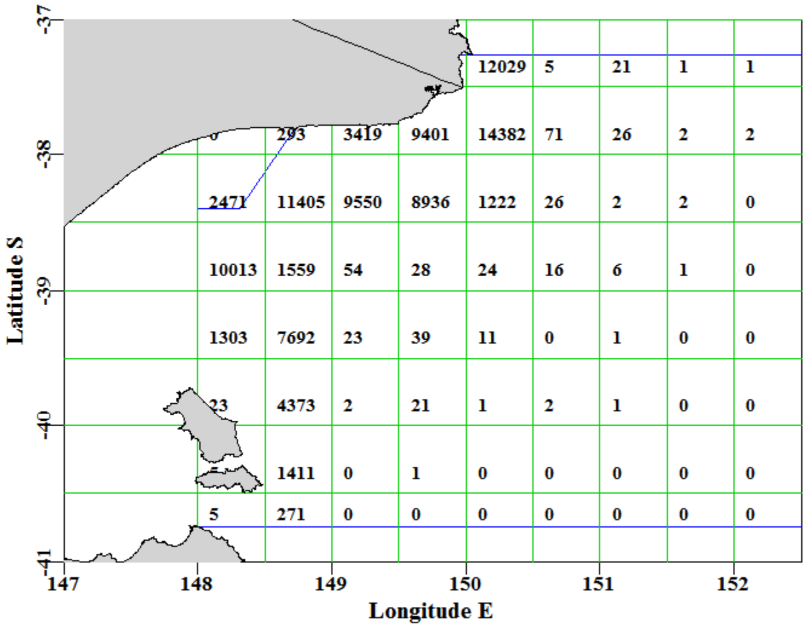

Figure 7. The number of trawl records found in Zone 20 in depths between 0 – 700m between 1998 – 2013. The green boxes delineate 0.5° x 0.5° cells, the blue lines bound Zone 20 (the blue line along 148° longitude is obscured by a green line.

Table 7. The reported catch in tonnes of 18 different species within the South-East Trawl fishery (SET) between the depths of 0 – 700m from 1998 – 2013. The species are in order of their total catch over the 1998 – 2013 period. Bight Redfish is primarily a GAB species so its low reported catches are not surprising.

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
bluegrenadier	4040.626	7036.319	7358.901	7949.058	7833.517	7573.730	5740.850	4020.682	3349.483	3003.779	4013.259	3790.424	4382.990	4365.448	4419.834	4112.425
silverwarehou	2037.806	2747.858	3338.519	2832.551	3695.064	2783.549	3095.518	2574.797	2095.424	1738.411	1323.926	1160.957	1159.830	1075.991	761.259	570.627
flathead	1130.912	1319.745	1872.727	1509.254	1682.386	1859.948	1852.090	1575.868	1485.277	1311.592	1530.055	1197.326	1217.610	1239.146	1355.048	939.712
pinkling	1351.939	1336.780	1246.068	1028.659	828.567	860.933	721.002	610.344	604.443	550.686	586.633	497.793	555.960	669.568	627.772	465.220
jackassmorwong	694.520	788.358	743.154	660.598	700.040	621.148	634.249	644.234	656.550	470.145	550.120	356.915	285.986	310.513	302.226	241.472
redfish	1537.784	1099.214	745.823	727.945	793.658	578.739	455.830	463.644	306.969	211.461	181.606	155.832	148.461	84.449	64.452	61.438
mirrordory	347.589	298.085	165.498	235.540	437.931	564.350	457.466	529.083	364.249	267.260	377.850	464.073	563.748	500.732	354.704	263.869
bluewarehou	818.327	307.289	390.964	254.063	282.155	221.571	224.844	279.457	365.700	165.218	151.077	126.909	117.559	92.200	44.765	63.346
oceanjacket	68.164	89.686	73.396	64.667	200.276	189.597	314.435	345.591	304.587	287.075	321.750	378.555	296.959	278.835	344.370	266.264
oceanperch	256.054	271.813	248.834	252.808	221.133	252.427	217.341	220.864	148.346	130.756	132.425	136.095	156.961	152.004	143.953	132.006
rrp	192.102	345.947	401.304	230.745	418.154	167.558	168.379	153.280	179.074	115.909	74.294	68.259	94.752	108.550	123.373	201.593
silvertrevally	177.427	115.105	124.326	227.601	209.269	281.602	369.105	244.125	213.964	128.915	101.431	140.119	201.690	181.558	129.821	114.126
gemfish	312.513	293.769	298.526	233.271	127.397	174.123	165.509	178.138	169.439	129.932	159.614	117.950	151.140	102.401	98.176	81.291
johndory	99.196	122.030	152.703	119.203	138.522	141.852	150.085	92.490	75.378	53.288	105.207	83.390	53.519	60.247	58.239	53.166
schoolwhiting	33.455	52.919	209.896	188.911	128.293	192.536	91.536	133.687	141.568	83.296	68.531	30.359	38.401	50.030	40.415	46.144
sawshark	21.911	28.305	45.754	33.839	50.166	52.216	59.731	64.904	91.570	53.417	52.741	57.532	48.954	47.050	46.691	46.036
gummyshark	25.522	25.842	39.044	35.327	42.389	41.947	41.957	39.579	50.680	40.349	57.562	50.603	45.794	52.111	58.285	53.537
blueeye	78.573	88.916	70.936	66.823	53.592	20.291	42.248	28.876	53.800	35.888	27.972	36.683	35.394	20.750	10.290	22.708
deepwaterflathead	5.680	14.190	30.390	24.299	26.265	20.370	40.792	41.179	55.953	23.335	24.098	26.297	21.747	34.654	30.321	60.850
schoolshark	15.877	12.548	14.963	14.139	16.508	12.384	12.101	6.535	9.612	6.802	8.191	12.726	11.574	13.619	10.315	18.002
bightredfish	0.000	0.000	0.000	0.000	0.005	0.000	0.630	0.000	3.588	0.000	0.008	0.000	0.023	0.000	0.000	0.159

By selecting one or more of the 0.5° cells (**Figure 8**, **Figure 10**, and **Figure 11**) containing a large number of records the co-occurrence of familiar species can be examined in detail on a month to month basis. The companion analysis is conducted at a smaller geographical scale 0.5° x 50m depth class, so if there are no regular patterns at the larger scale there would be no expectation that they necessarily exist at a smaller scale.

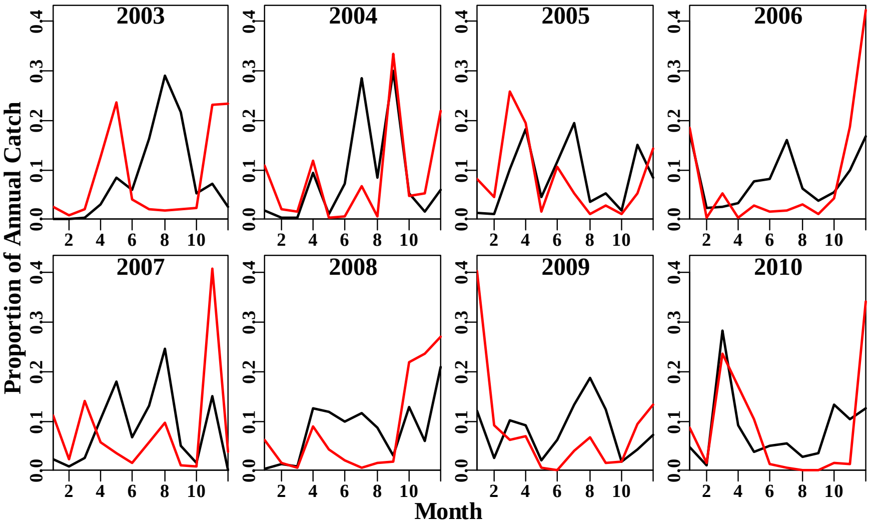

Figure 8. The proportional distribution of catches of Flathead (black lines) and Jackass Morwong (red lines) by month from 2003 – 2010. The correlation between the two species is just significant (at the 5% level) in 2004, 2006, and 2010 but insignificant in other years.

Flathead is listed as a companion to Jackass Morwong (Klaer and Smith, 2012) so the seasonal pattern of their relative catches might be expected to exhibit a reasonable degree of coincidence (**Figure 8**). It is clear that catches of these two species are sometimes correlated but overall the relationship between them is not consistent. When the seasonal data for each species, Flathead and Jackass Morwong, are plotted together (**Figure 9**) then the seasonal variation within the 0.5° cell is clear for both species but differs from June onwards. Some months appear to have less variation but those occur when there is almost no catch of a given species.

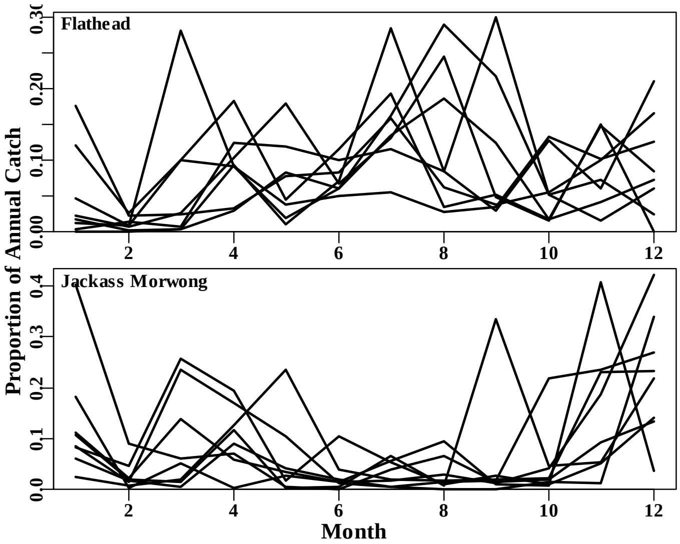

Figure 9. The seasonality of Flathead and Jackass Morwong catches from 2003 – 2010 (same data as in **Figure 8**) plotted to illustrate seasonal variation within species.

Blue Grenadier is listed as being associated with Silver Warehou in Klaer and Smith (2012), which implies a weaker relationship than being a companion species and these species are certainly less correlated than Flathead and Jackass Morwong(**Figure 10**).

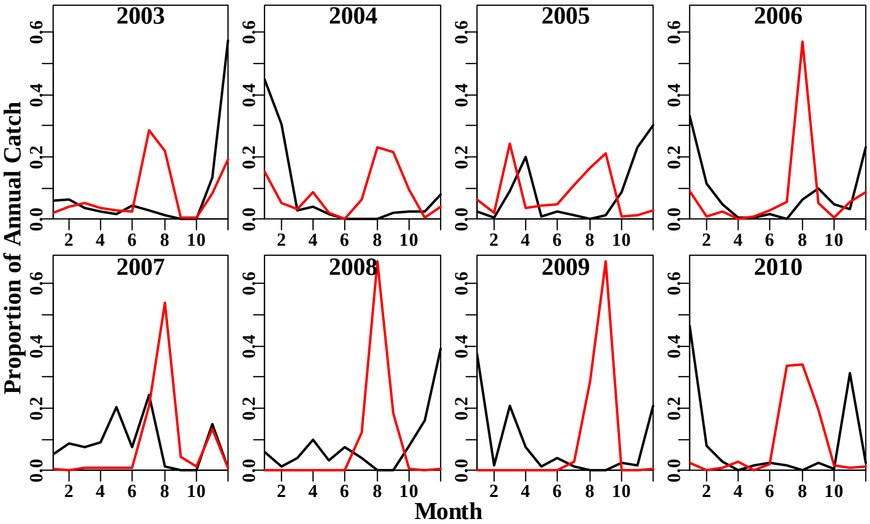

Figure 10. The proportional distribution of catches of Blue Grenadier (black lines) and Silver Warehou (red lines) by month from 2003 – 2010. The correlation between the two species is not significant in any year.

Finally, in the 0.5° x 0.5° cell within zone 20 containing the most data (**Figure 7**) Flathead and Pink Ling also exhibit significant correlations only occasionally (**Figure 11**).

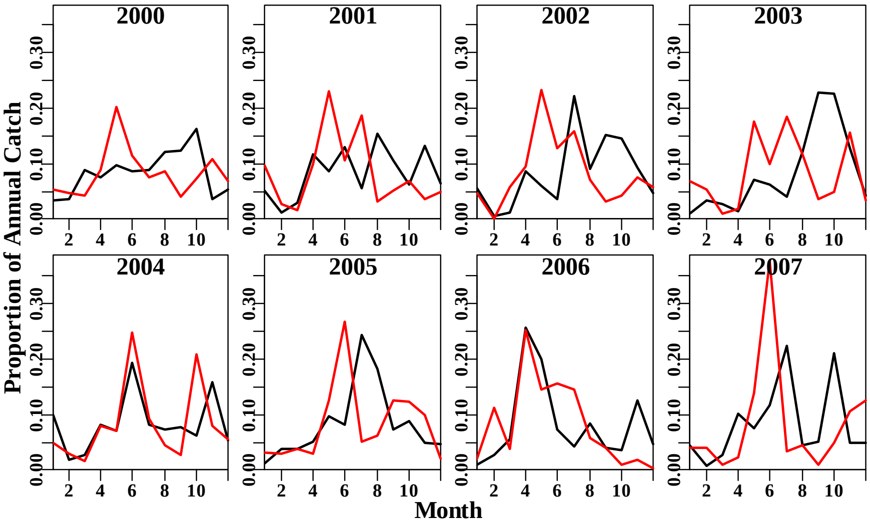

Figure 11. The proportional distribution of catches of Flathead (black lines) and Pink Ling (red lines) by month from 2000 – 2007 from the 0.5° cell selected by Long 150° and Lat -37.5° (see **Figure 7**). The correlation between the two species is only significant (at the 5% level) in 2004 and 2006.

When the seasonal data for Flathead and Pink Ling are plotted together (**Figure 12**) the seasonal variation within the 0.5° cell appears to change from year to year for Flathead, while Pink Ling exhibits a more consistent seasonality, but even then it also expresses a high degree of variation in any particular month.

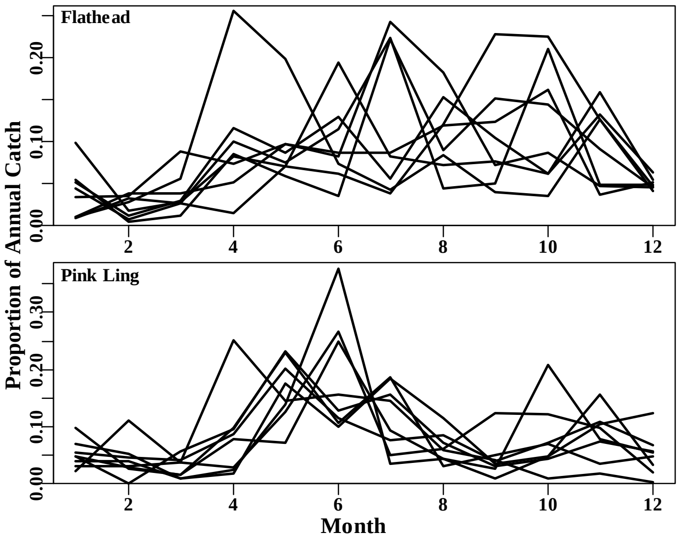

Figure 12. The seasonality of Flathead and Pink Ling catches from 2000 – 2007 (same data as in **Figure 11**) plotted to illustrate seasonal variation within species.

At larger geographical scales the catches of various species can appear to be correlated at times (**Figure 8**) but if the 0.5° cell is sub-divided into smaller areas this can break any such regular association. When the 0.5° cell containing the most data is sub-divided into its 50 m depth strata the different depth distribution of different species can easily be illustrated (**Figure 13**). Variation in the relative catch across depths within months across years is more variable in Flathead than it is in Jackass Morwong and Pink Ling, although when catches occur at all, for all species variation between years remains high (**Figure 13**). This implies that depth is a relatively strong predictor of what species may be caught but so much variation remains across years and across 0.5° cell, that the assertion that fishers have prior knowledge of where and when to catch different species appears to be asserting more than can be supported by the available data.

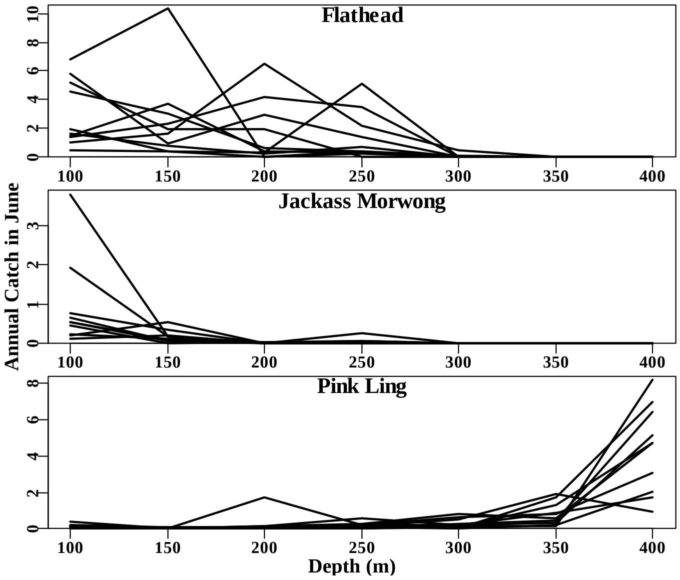

Figure 13. The depth distribution of catches in the month of June, with each line representing the month of June across the years 2004 – 2013. Here absolute catches are represented to illustrate the variation across years.

Given that the companion species analysis relies on the assumption that combinations of species can be expected to occur together in relatively small area in a consistent fashion, these findings raise concerns over the generality of the approach.

6.2.4 Zone, Long/Lat, Depth, and DayNight Strata

The homogeneity (or heterogeneity) of the species composition at the finest level of stratum (that is at the 0.5° × 50m depth category × month × time-of-day level) was tabulated to examine the assumption that species composition at the finest strata sub-division is predictable. To ensure that the maximum amount of data was available to examine the homogeneity of the species composition, strata sub-divisions were sequentially selected on the basis of which contained the most records (**Table 8**).

There were 14382 records across 1998 – 2013 in the Long 150° and Lat -37.5° cell, but when this was restricted to the month with the most records (it was May with 1719) and within May, the depth with the most records (100m with 465), then the numbers of records per year in each of the DayNight categories is greatly reduced (**Table 8**). This reduction, of course, leads to even greater paucity of data in each {0.5° × 50m × month × time-of-day} stratum for cells containing even fewer records (**Figure 7**).

Only the 'day-time' and 'mixed' categories within the DayNight factor had sufficient data to enable a comparison between years for the month of May (all other months had fewer data). By tabulating the catches of each species within the stratum in each year the homogeneity, or otherwise, of the species composition can be illustrated simply by scanning across tables of species catches against years (**Table 9** and **Table 10**).

Table 8. Selecting log-book data from trawl shots in the SESSF in cell Longitude 150°, Latitude -37.5°, which contains 14382 records across the years 1998 – 2013. The DayNight categories are D = day-time, M = mixed, N = night-time, and U = unknown (there were only 2 unknown records).

Across Years		Month May		In May, in Depth 100m			
Month	Records	Depth	Records	Year	D	M	N
1	774	0	1	1998	26	14	7
2	736	50	58	1999	48	29	11
3	867	100	465	2000	14	18	5
4	1498	150	241	2001	14	3	4
5	1719	200	186	2002	5	7	0
6	1381	250	158	2003	10	6	2
7	1339	300	64	2004	20	7	3
8	1432	350	100	2005	12	12	5
9	1230	400	278	2006	12	4	4
10	1461	450	105	2007	1	9	5
11	1251	500	55	2008	8	12	6
12	694	600	2	2009	2	4	3
		650	6	2010	8	14	10
				2011	8	7	4
				2012	6	7	5
				2013	10	22	10

Catches during the day-time averaged about 2,600kg per year from 2000 – 2013 (**Table 9**), whereas during the mixed period it was 4,320 kg per day from 2005 – 2013 (**Table 10**). The average catch across both day-time and mixed was variable but averaged about 6,800 kg per year from 2004 – 2013 (**Figure 14**), which indicates that the introduction of the HSP in 2007 had little direct affect upon catches in this particular stratum, although 1998 and 1999 appear to have produced exceptionally high catches relative to later years.

Table 9. The relative catch (kg) of those species for which more than 1000kg was landed across the years 1998 – 2013 in the stratum Zone 20, longitude 150°, latitude -37.5°, in depths 100 – 150m, in the month of May, during the day (daynight category 'D').

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
flathead	836	778	948	744	122	580	1175	705	850	100	2294	500	1960	970	755	1125
jackassmorwong	2752	8229	774	562	120	465	1177	695	550	150	661	150	694	235	1125	1330
redfish	3949	5161	1045	715	490	582	1285	85	150		15		397	67		5
silvertrevally	80	342	209	1578	32	15	304	90	5				15	1		22
silverwarehou	191	660	19	21		60	30	30	5		138	30	100	1		
johndory	393	549	378	428	55	242	1264	30	875		210	105	91	137	72	125
oceanjacket	231	265	31		10	25	460	83	913		573	135	728	135	143	501
bluewarehou	1020	1025	205	15		82	6	360	5			40	8	156		45
Total Catch	9452	17009	3609	4063	829	2051	5701	2078	3353	250	3891	960	3993	1702	2095	3153

Despite average catches remaining noisy by roughly stable the relative species composition varied greatly in both DayNight categories. The DayNight category is clearly important with respect to predicting which species might be caught and which might not, for example, very little Pink Ling (< 1 t across 1998 – 2013) was caught during the pure day-time hours, whereas silver trevally were only caught during the day-time.

Table 10. The relative catch (kg) of those species for which more than 1000kg was landed across the years 1998 – 2013 in the stratum Zone 20, longitude 150°, latitude -37.5°, in depths 100 – 150m, in the month of May, during the mixed daynight category 'M'.

Species	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
flathead	448	1160	1912	250	635	455	525	1345	430	1220	4040	410	1620	1220	1322	3230
jackassmorwong	2091	3504	1524	420	125	119	488	607	600	4070	745	730	1729	1130	1150	1499
pinkling	357	241	422		39	58	141	114	13	11	50	21	114		13	106
redfish	2129	5011	1740	310	396	180	350	2248	345	526	101	45	523	124	115	141
johndory	125	191	364	20	191	67	179	93	100	20	135	70	57	32	88	174
oceanjacket	39				40	10	65	975	60	86	705	1500	80	90	225	1530
bluewarehou	381	1484	182			51	190					20	577	105	20	435
Total Catch	5570	11591	6144	1000	1426	940	1938	5382	1548	5933	5776	2796	4700	2701	2933	7115

However, within the same {0.5° × 50m × month × time-of-day} stratum there was relatively large variation in species composition between years (**Table 9** and **Table 10**). The predictability of the relative abundance of particular species would appear to be low. Flathead and Jackass Morwong occur in every year during the day-time and in mixed, with John Dory and Redfish also occurring every year in mixed, but all other species are occasionally missing.

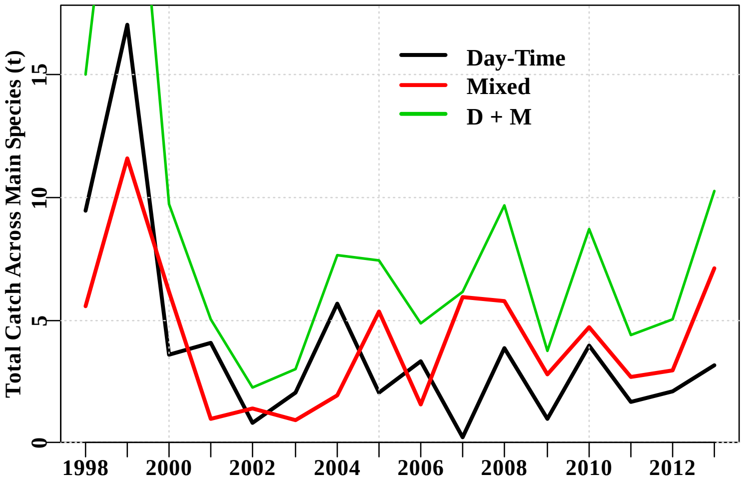

Figure 14. The total catch as tonnes across all the main species within each year within each DayNight category; see **Table 9** and **Table 10** for the main species in each of the two categories. The average combined total catch from 2004 – 2013 was 6,799 kg per year.

When the data for each record within particular years is considered (e.g. **Table 11**) there is also relatively marked variation between the number of records with respect to both species composition and relative abundance. Some species, can be highly variable in terms of relative abundance (**Table 11**) with, for example, Ocean Jackets varying over an order of magnitude (35kg – 405kg) across different individual records and Flathead by even more (10kg – 300kg).

Table 11. The species composition of the 12 records contained in the selected {-37.5° × 100m × May × day-time} stratum in 2006, sorted in order of the most abundant species. Values are kg.

Species	rec1	rec2	rec3	rec4	rec5	rec6	rec7	rec8	rec9	rec10	rec11	rec12	Total
oceanjacket	405		90		75	52.5	45	135	45		35	30	912.5
johndory			20		25	300	50	330	50	60	20	20	875
flathead	60	10	100	300	120	30	30	60	20	60	40	20	850
jackassmorwong	70	40	50			90		120	30	120	20	10	550
redfish			30		10			30			80		150
sawshark					10	30							40
gummyshark						30							30
silvertrevally								5					5
silverwarehou								5					5
bluewarehou								5					5

6.2.5 Recent Failure to Catch TACs

In recent years there has been a growing issue of fishers not catching the full allocation of the TAC each year for almost all species. This has importance for the companion species analysis as this undermines an important assumption of the analysis, which is that the relative proportions of combinations of species are predictable if it is known where and when and how deep a fisher is fishing. Hence, if fishers are changing their fishing, targeting, or retaining behaviour then any relationships between species on which the analysis is based will become either less certain or even broken. The extent of this failure to catch the TAC is therefore of importance to the companion species analysis.

Some quota inefficiency can be expected to arise from the TAC being divided among many quota holders, and fishers now needing to reconcile their catches each month against quota held or leased. This reconciliation requirement means that it is possible for each fisher to have small amounts of quota left over at the end of the quota year simply through the difficulty of matching their available quota to their varied landings. However, the failure to catch the TAC more recently is now taken to reflect something unrelated to the minor fluctuations in individual fisher's quota holdings (**Figure 15**).

It is known, for example, that the major failure to catch the Blue Grenadier TAC in 2014 was due to the failure of the larger factory vessels to visit the fishery from New Zealand (the stated reason being 'for operational reasons') and as those vessels tend to take most of the quota their absence had a marked effect. Nevertheless, the catch of many species, including Blue Grenadier, has been well under the TAC since 2005 – 2014. There can be a difference between the TAC and the 'Actual TAC' which is brought about by the notion of 'overs and unders'. If a proportion of a fisher's quota remains uncaught in one year, for many species a proportion of that can be carried over into the following year. Similarly, if some is over-caught then this can be debited from the following year's quota entitlements in the following year; hence 'overs and unders'. The specifics of these regulations can be modified for each species individually. For example, School Shark, Blue Warehou, and eastern Gemfish each have as a condition in their rebuilding strategy that there are no 'under or over' provisions in their by-catch TAC setting process (**Figure 15**). With redfish, this has only just had a rebuilding strategy developed (AFMA, 2015c), and so the removal of the under or over provisions has yet to come into play.

Except for western Gemfish, out of the 25 illustrated (the top 25 in terms of accumulated catch over 2005 – 2014, excluding orange roughy) the proportion of the Actual TAC taken is never greater than that of the nominal TAC (**Figure 15**). Some species, are consistently close to their Actual TAC, including Flathead, Pink Ling, Blue-Eye Trevalla, and School Shark, but four out of 25 is not a large number.

Good explanations are available for why the TAC for some economically important species is not being completely taken. Gummy Shark, for example, has failed to achieve its TAC since about 2011, which is also when the TAC for School Sharks was reduced from 240t to 175t. Industry report that avoiding School Shark is leading to them failing to catch all of their Gummy Shark quota. In addition to this effect, there have been large changes in the management of the Gummy Shark fishery in South Australia because of perceived interactions between gillnets and dolphins and Australian sea lions

(Goldsworthy *et al*., 2007). This has led to a large drop in Gummy Shark catches in South Australia that has not been completely replaced by the shift to hook-based catching methods that occurred following the banning of gill nets.

A different example is with Bight Redfish, which is primarily taken in the Great Australian Bight and has exhibited a strong decline in the proportion of its TAC being taken each year. This appears to be a reflection that earlier stock assessments (Klaer, 2012) could only be based on relatively uninformative data, although the most recent assessment (Haddon, 2015b) is beginning to be informative about unfished spawning biomass levels and this is leading to a reduction in the estimated RBC. The original RBC was 4400 t, with a TAC of 2358t; which was much lower than the original RBC because the RAG appreciated that the RBC estimate was poorly informed by the available data. With the new assessment, even though the stock was still estimated to be well above the Target Reference Point of 48%B_0 there was a reduction in the RBC down to 826 t, with a predicted long-term yield of 537 t (Haddon, 2015b). In this case, therefore, the TAC had been mistakenly set far too high, even though the RAG attempted to allow for the influence of relatively uninformative data on the stock assessment.

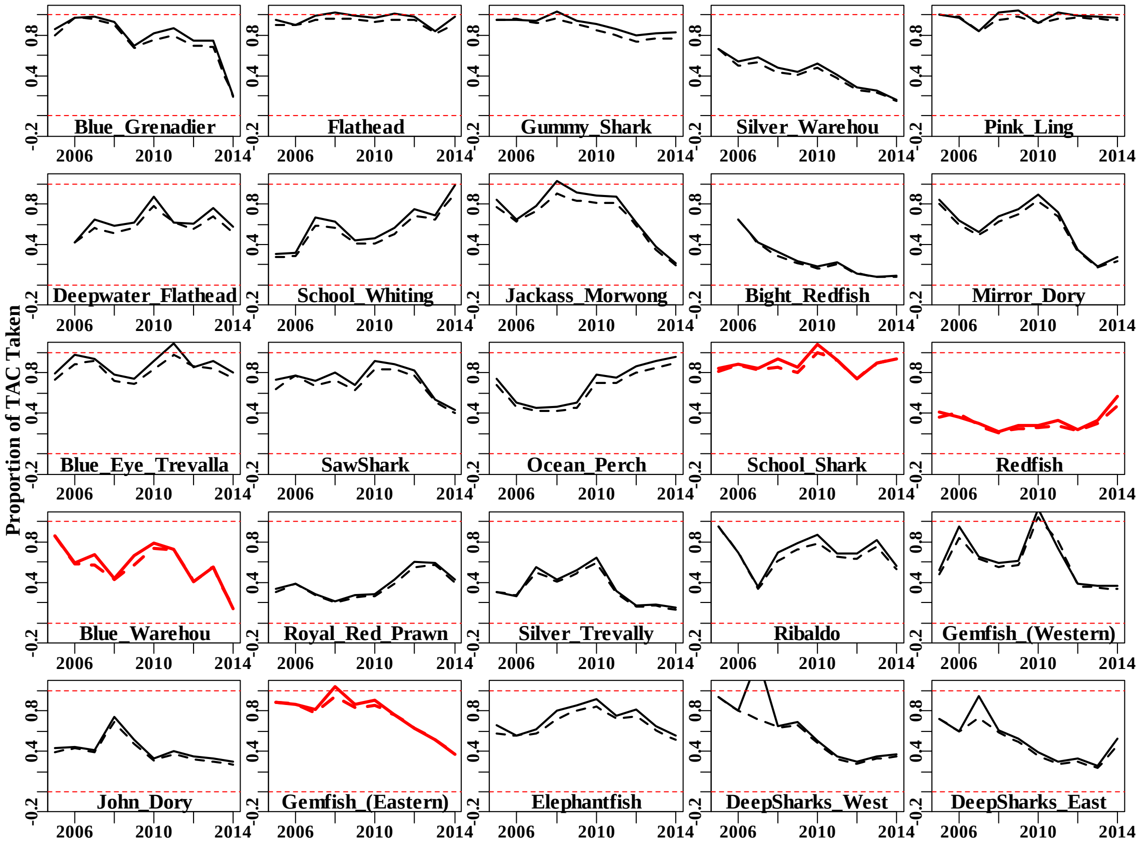

Figure 15. The proportion of the TAC caught each year from 2005 – 2014 (solid lines). The ‘actual TAC’ can be both larger and smaller than the TAC due to carry overs/unders, hence some catches are larger than the TAC. The dashed lines are the proportions based on the Actual TAC for each year while the solid lines are the nominal TACs. The red lines relate to severely depleted species. All data from the CatchWatch website http://www.afma.gov.au/fisheries-services/catchwatch-reports/ using the end of fishing year reports.

Species such as Saw Sharks and Elephant Fish are typically by-catch species, which are easily targeted but are of low value and are unwanted by fishers, especially as they can be potentially damaging to their fishing gear. It is thus not surprising that their TACs are rarely caught. Other species, such as John Dory, are by-product species which are difficult to target. The proportions of the TAC taken for School Whiting and Ocean Perch have been increasing in recent years and this reflects changing fishing behaviour within the State fisheries and a growing market for the larger Ocean Perch. For all of these species it is possible to provide a degree of explanation for why their TACs are not always taken. Despite this, the degree of failing to take the TACs, especially in 2014, still appears to be greater than should be the case.

The fishery for each species tends to have its own circumstances and idiosyncrasies that make the production of generalities difficult. Nevertheless it is clear that there are imbalances in the quota system and the relative catch of the different species taken in the SESSF trawl fishery (**Figure 6** and **Figure 15**). How much of the observed changes in the proportional catch of different species in the trawl fishery (**Figure 5**) are due to whatever is leading to the failure to catch the TAC of each species remains unknown, but it nevertheless constitutes evidence that the interpretation of the companion species analyses needs to be given careful consideration.

6.3 Risk Assessments for Rebuilding Species

6.3.1 Introduction

This project's second objective states:

> *Conduct risk assessments to determine acceptable levels of incidental catch TACs for species under rebuilding strategies (e.g. School Shark, Blue Warehou and Gemfish as case studies) within the parameters of the Harvest Strategy Policy.*

This objective is attempting to approach the question:

Do current allocated catches imply annual fishing mortalities greater than can be currently sustained?

The current HSP focuses on fisheries management and how to achieve sustainable utilization of living marine resources. However, implicit in many of the HSP's requirements and expectations are assumptions concerning population dynamics. One of the most important assumptions is that once a fished stock is depleted below 20%B_0, and so requires rebuilding, once catches are greatly reduced then rebuilding will happen as a matter of course. That this is merely an assumption is reinforced by the fact that a number of recalcitrant species have had their catches greatly reduced but they do not appear to be recovering. The population dynamics which predicts this outcome, and is assumed in the HSP, is deterministic as well as overly simplistic and while, fortunately, this is sufficient for many species there are obviously exceptions.

In this section a case study of the assessed state and subsequent predicted dynamics relating to Blue Warehou (*Seriolella brama*) will be produced in some detail. This will provide a specific context into which to place a discussion of options.

6.3.2 The Commonwealth Harvest Strategy Policy

In the Commonwealth Harvest Strategy Policy (HSP), when a species is assessed as being below the limit reference point (LRP; 20%B_0 or its proxy) then targeted fishing is not to occur. As stated in the HSP:

> *"The biomass limit reference point B_{LIM} is a key component in the HSP and will generally play a key role in development of harvest control rules. It defines the point at which a stock will be defined as "overfished", and the point in the harvest control rule below which there will be no further targeted fishery on that species, and a stock rebuilding strategy has to be set in place."* (DAFF, 2007, p23)

In practice, the cessation of targeted fishing is the first step in developing a detailed rebuilding strategy for any species which remains below the LRP persistently. Currently such species include Blue Warehou, School Shark, and eastern Gemfish, although recently a rebuilding strategy was developed for Redfish (AFMA 2015c).

Despite being under rebuilding strategies the three recalcitrant species listed do not appear to be recovering as intended by the HSP. Workshops have been dedicated to the three different species but in each case no single or combination of reasons has been clearly identified as the cause of the apparent failure of these stocks to recover. It is necessary to use terms such as ‘appear’ and ‘apparent’ because the very act of setting only a non-target catch limit (TAC) implies the commercial fishing industry will be avoiding the species as best they can. While this certainly leads to reduced catches it also means that managers and researchers may begin to operate without updated data or, potentially worse, operating with only unreliable or non-representative data.

The reasons why the quality of available data may decline are obvious. As fishers are avoiding species, commercial catch and effort data for that species can no longer be expected to hold any relationship with relative abundance through time. In addition, while it is possible to collect age- and length-frequency samples, either on board or in ports, whether such samples remain representative of the remaining stock or even the fishery also needs to be questioned (**Figure 2** and **Figure 16**); it is also the case that there is little information in such composition data concerning relative abundance. It may be the case that any such samples are representative of the catches (although if catches become unusual events then being present to sample catches becomes difficult) but as the catches become sporadic they may not represent the stock. Unfortunately the three recalcitrant species commonly exhibit schooling behaviour and hence tend to be patchy both geographically and through the year, so they are also not particularly amenable to being appropriately sampled in the current series of trawl surveys occurring in the SESSF. Designing any survey to assess the relative abundance of such schooling and patchily distributed species remains extremely difficult. For example, the species specific survey for Blue Warehou in 2005 (Hudson and Knuckey, 2006; Haddon, 2007a, b; Punt, 2007) essentially failed to provide useful data for assessment mainly for operational reasons (during the period of the survey Blue Warehou did not appear in the survey strata over their main fishing sites). The survey attempted to account for their geographical patchiness and patchiness in time and while it succeeded to some extent in one region it failed in another. Even though the survey data were included into the stock assessment at the time (Punt, 2006b), the variation inherent in the survey data essentially prevented that data from having any influence on the results of the assessment.

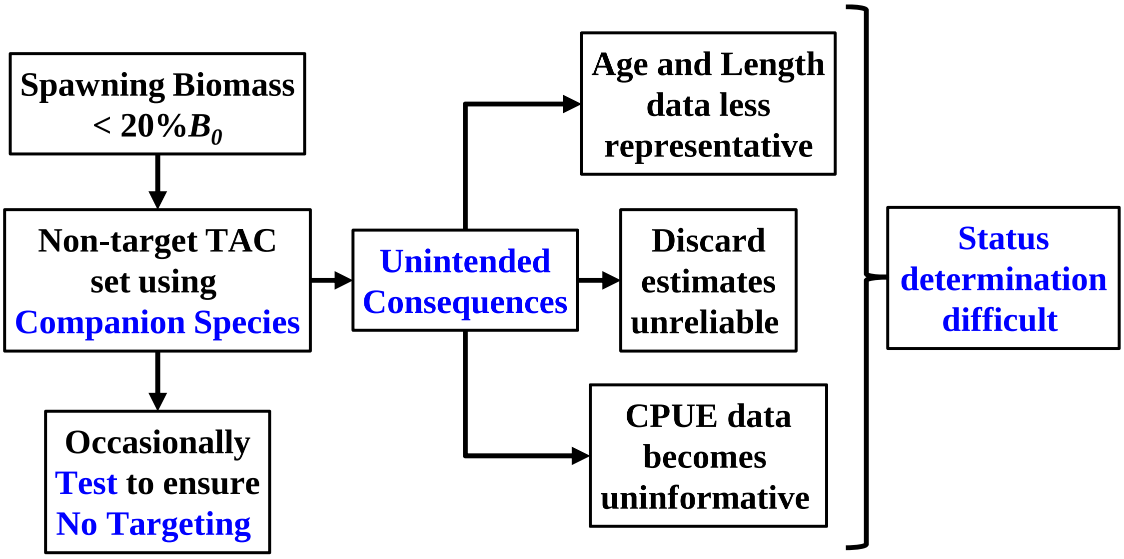

Figure 16. An over-view of the implications and unintended consequences for monitoring stock status of placing a species into a rebuilding plan.

6.3.3 The Failure to Rebuild

There are three main hypotheses (there are others not listed here) that have been put forward as potential explanations for the failure of species to rebuild, with extra hypotheses cited in particular cases:

- The species are in fact recovering but the avoidance is so effective that we remain unaware of the recovery.
- The productivity of the stocks has declined in response to other species taking their place (e.g. Silver Warehou instead of Blue Warehou) or because environmental changes, especially on the east coast of Australia, have led them to be biologically less productive.
- The remaining non-targeted catches remain too high for such depleted species to recover, either through the landed catches or discards being too high in aggregate.

These are all difficult to test, once again through the lack of the availability of representative data from the fishery or from fishery independent surveys. The lack of reliable information may be preventing any recovery from being noticed (hypothesis 1) but there may be no consistent reports of increased discards, which would act as a measure of increased biomass or availability.

The other two hypotheses concerning reduced recruitment or the harvest rate remaining too high are, however, potentially open to exploration. In the absence of useful data other than catches it remains possible to use stock assessment models to make projections from the last formal assessment (as was done by Thomson, 2013, for School Sharks). Such projections can be extended and used to determine whether plausible recruitment or catch scenarios are at least inconsistent with current observations. For example, an assessment of Blue Warehou was made in 2008 (Punt, 2009) and this can be projected to the present day. Assumptions, such as that the productivity (recruitment levels) of the stock today remains the same as it was estimated to be in the 2008 model, and/or that the reported catches are not too high and are an accurate reflection of the current total kill of the species, can be tested by altering the assumed recruitment levels and by artificially increasing the level of catches since it was last assessed.

Using Blue Warehou as an example, the latest stock assessment (Punt, 2009) was projected forward removing the more recent known catches and modifying different aspects of the assessment to see the effects of different recruitment levels since 2005, which was when they were last estimated. This will provide some insight into what degree of change in the productivity, if any, would be required to be consistent with a lack of recovery. Alternatively, if recent catches were in fact under-estimates, perhaps because discards have been under-estimated, it is possible to determine by what proportion they would have to be incorrect for a lack of recovery to occur. This examination will at least indicate whether hypotheses suggesting either changes in recruitment/production or that the harvest rate is too high, or that there has been incorrect reporting of catches are implausible or instead could potentially contribute to the problem of a lack of perceived recovery.

6.3.4 Blue Warehou Stock Assessments

Early assessments of Blue Warehou were relatively informal and involved considerations of cpue and sometimes the application of catch curves. Smith (1994) summarized what was known about Blue Warehou and concluded that "The current status [in 1994] of the resource is unknown."

The first formal stock assessments for Blue Warehou occurred in 1997 and 1998 and were based on the application of a Virtual Population Analysis to catch-at-age and standardized fishing effort data (Punt, 1998). From 1999 onwards, assessments of Blue Warehou (Punt, 1999, 2000; Punt and Smith, 2005; Punt, 2006a, b) have been based on the 'integrated analysis' approach (see Maunder and Punt, 2013; Methot and Wetzel, 2013). Information on catches, discard rates, catch-rates, and the length/age composition of the discards and the landed catch were included in the 1999, 2000, 2004, 2005 and 2006 assessments. The 2006 assessment (Punt, 2007) was the first to use the age- and size-structured stock assessment package Stock Synthesis 2. The last formal assessment conducted using a version of Stock Synthesis 3 (SS3; a formal stock assessment package; Methot and Wetzel, 2013) was made by Punt (2009).

He stated:

> *"The results for the eastern stock are qualitatively identical to those from the most recent three assessments; the stock is depleted to well below the target reference point and there is no evidence for a recovery. In contrast to the situation for the eastern stock, the western stock recovered from below the overfished threshold of $0.2B_0$ to close to the B_{MSY} proxy of $0.4B_0$ in 2005, but has declined since owing primarily to lack of good recruitment. The model predicts that the western stock will drop below the overfished threshold by 2008 if the landed catches for 2008 are as assumed. The assessment is more data-poor and less reliable than prior assessments because the most of the data for 2007 are unusable.*(Punt, 2009, p53)

6.3.5 Base Case

The array of data used (**Figure 17**) and the base case fit (**Figure 18**) differs somewhat from that by Punt (2009), including somewhat higher catches in some years, a revised CPUE series, and a larger assumed standard deviation of 0.275 around the catch rates, which enabled the CPUE from 1989 to be included in the calculations (they were previously excluded; **Figure 18**). As with the assessment in 2008 (Punt, 2009), the outcome in 2008 of the re-analysis was that the western stock was bordering on the limit reference point (**Figure 18**). The model predicts recruitment at slightly above average levels in 1994 but otherwise, from 1987 – 2005 predicted recruitment levels have been well below the unfished recruitment levels. In the model, during 2006 – 2008 recruitment reverts to unfished levels. It does this because any recruitment in the final three years, 2006 – 2008, would not be present for long enough to enter the recruited biomass and alter the model dynamics so they are not estimated; there is too little information in the fisheries data to enable the relative abundance of new recruits to be well estimated in those years. Give the estimates from 1987 – 2005 are generally well below the unfished average recruitment, the reversion to this unfished average appears implausible.

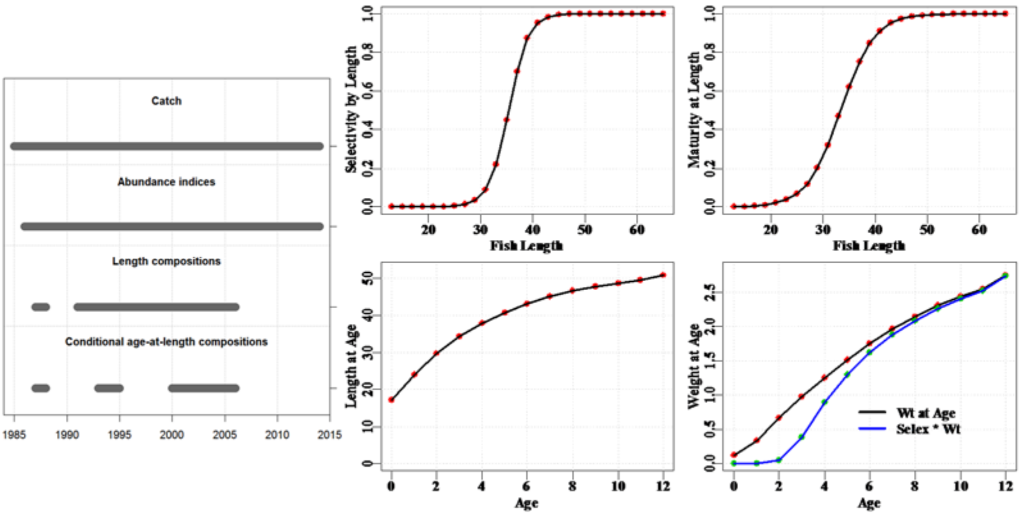

Figure 17. Data availability summary by type and year for the western Blue Warehou fishery, along with some of the biological and fishery characteristics.

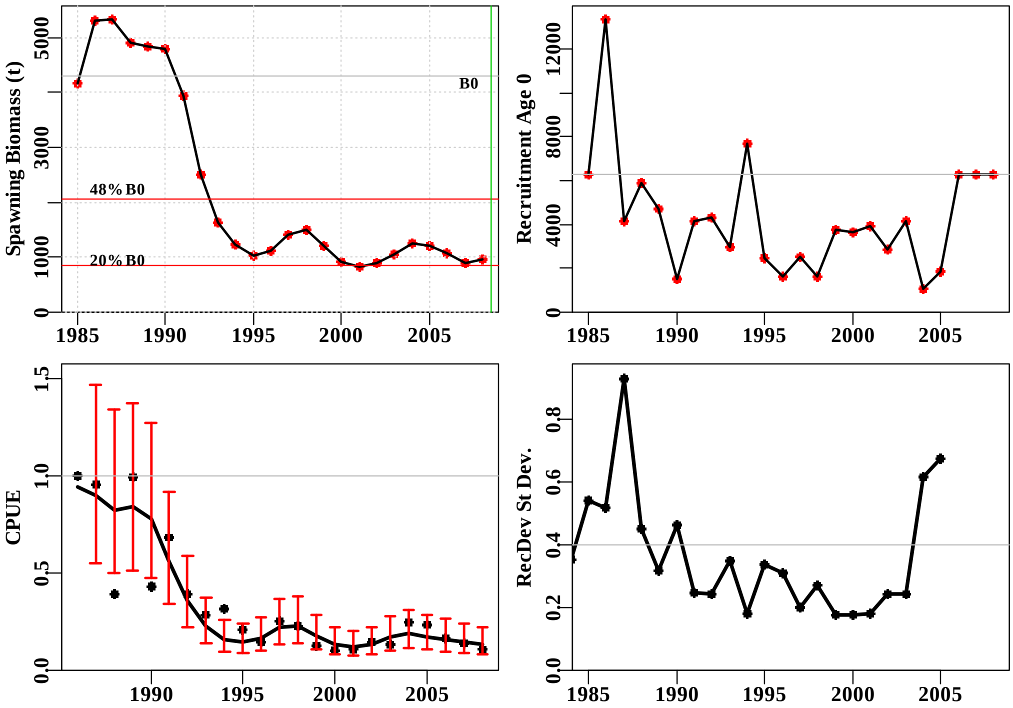

Figure 18. Summary output of the assessment for the western Blue Warehou trawl fishery. The predicted depletion level in 2008 was very close to 20%B_0 but CPUE was declining and, in 2005, recruitment levels had been below the expected long term average for 18 years (except in 1994). Note the assumption of a return to unfished recruitment levels in the years 2006 – 2008 when recruitment deviates are not estimated (top-right).

6.3.6 Projection with Unfished Average Recruitment

Generally, when projecting an assessment forward if the projection is only for a very few years then adopting the average unfished recruitment levels will not influence the outcome because it takes a number of years for new recruits to enter and influence the fishery. Hence the general approach used to check for breakouts in species that have multi-year TACs (Klaer *et al*., 2015) remains valid. However, in the Blue Warehou base-case the recruitment deviates (the expected deviation from the average recruitment expected from the stock recruitment relationship) are only calculated up until 2005. Thus, projecting the fishery forwards to 2014 involves assuming average unfished recruitment levels for the nine years 2006 – 2014. The last three years (2012 – 2014) will likely have no influence until 2015 and beyond but the effect of the years from 2006 – 2011 leads the model to predict that the stock should recover to about 80%B_0 given the catches that have been reported (**Figure 19**; **Table 4**).

In the base-case harvest rates averaged about 0.45 (~45%) per year from 1991 – 2008, and are often between 0.4 – 0.5, which was sufficiently high that even with the advent of occasionally relatively high estimated recruitment levels, as in 1994 (**Figure 19**), the stock depletion levels were kept down. It can clearly be concluded that, with the recruitment levels from 1987 - 2005, harvest rates needed at least to be lower than 0.45 for the fishery to be sustainable or recovery to occur. However, the combination of reducing catches from 2009 and the default assumption of increased recruitment levels from 2006 has led to the prediction of a remarkable and implausible level of stock recovery (**Figure 19**).

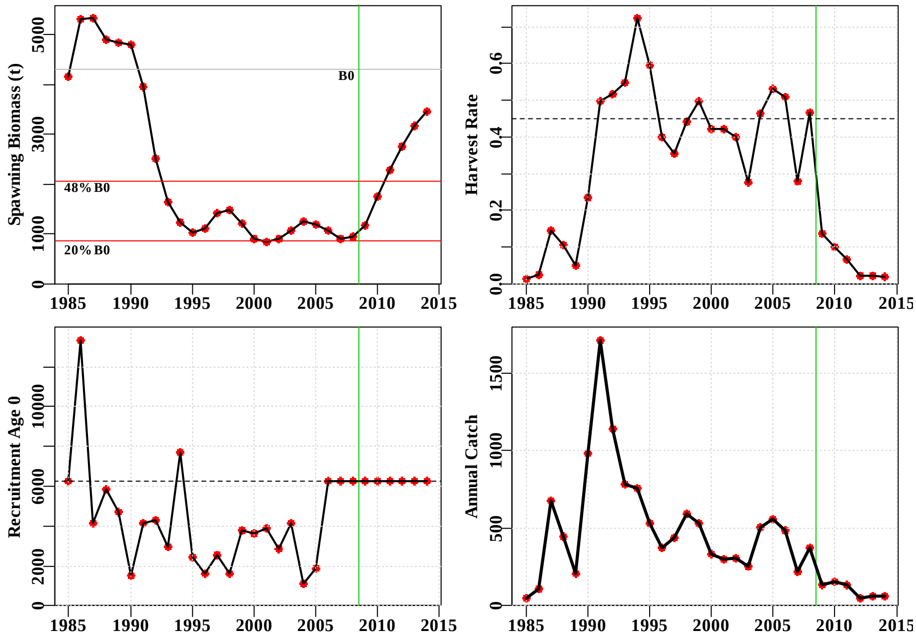

Figure 19. Summary output from SS3.24f for western Blue Warehou when the 2008 mode is projected forward using the recent catches. The dashed line in the bottom panel is the average unfished recruitment level (without an adjustment for log-normal bias-correction).

When the trajectory of recruitment levels are considered (**Figure 19**) it is clear that assuming the average unfished recruitment levels for projections beyond 2005 is ignoring the below average estimates that have occurred in every year since 1987, except perhaps 1988 and 1994. When values of recruitment are assumed that resemble the depressed average value across 1987 – 2005 the biomass recovery trajectory changes character (**Figure 20**).

6.3.7 Projections with Lower Average Recruitment

By replacing the assumed zero recruitment deviates (**Figure 19**) with particular, smaller, values, for example -0.2205 (the average recruitment deviate from 1987 – 2005), the expected recruitment is of course reduced in the projections and the predicted recovery only develops to 38.1% instead of the ~80% with zero recruitment deviates (**Figure 20**).

By examining the effect of different levels of average recruitment deviate the degree to which recruitment would have needed to be reduced to prevent stock recovery can be determined (**Table 12**; this has the assumption that catch reporting is accurate).

It would appear that for a change in recruitment to have led to no effective recovery since 2008, the recruitment levels from 2005 onwards would need to have been a low constant -0.8 (**Table 12**; **Figure 21**), which approximately corresponds to the lowest levels of recruitment estimated to have occurred since 1987.

With the lowered recruitment levels deriving from the recruitment deviate mean of -0.8, the stock productivity was reduced so the catches constituted a larger proportion of the available biomass. The predicted harvest rates in 2009 – 2011 were sufficient to drop the stock depletion somewhat lower than in 2008 and it was only when catches were reduced by almost 60% in 2012 that harvest rates in the order of 10% were achieved and the stock was predicted to begin a slow increase (**Figure 21**).

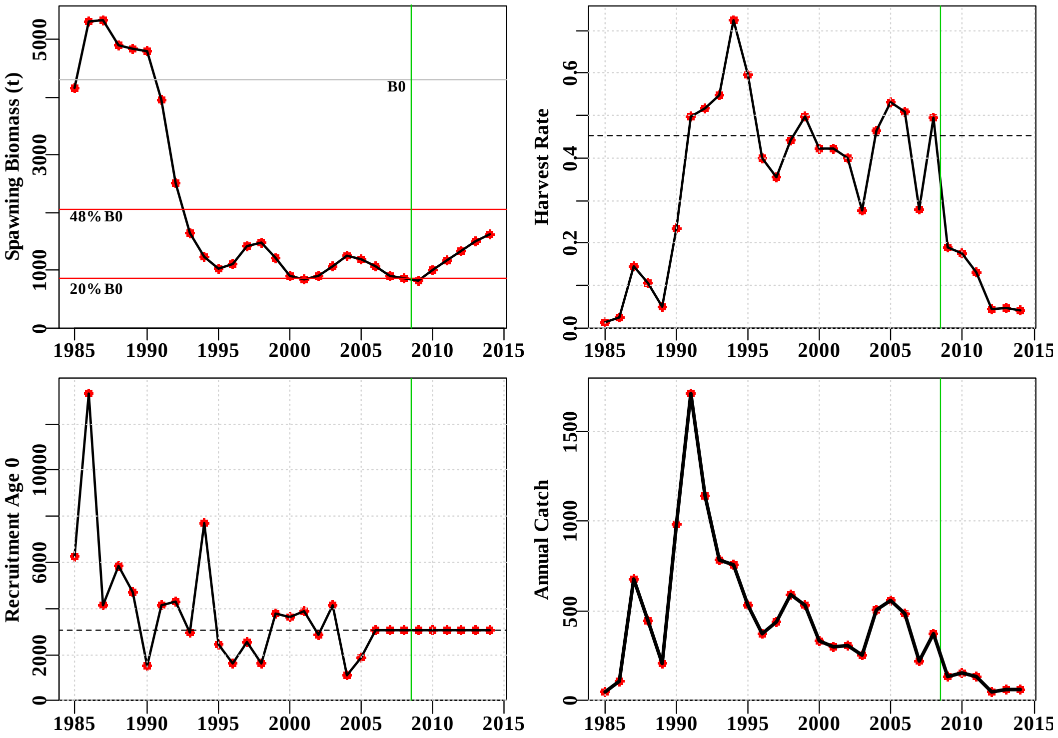

Figure 20. Predicted spawning biomass and recruitment levels for western Blue Warehou when the 2008 model is projected forward using the recent catches while setting the recruitment deviates to a constant average of -0.2205 (the average recruitment deviate from 1987 – 2005).

Table 12. The spawning biomass depletion level predicted for 2014 given different constant levels of recruitment deviations. The deviates from 0.0* to -0.8 include a log-normal bias adjustment for the recruitment levels. When there is no bias adjustment (0.0) this increases the predicted recruitment levels and distorts the outcome relative to the other values.

Average Recruitment Deviate	Proportion of Unfished Recruitment Level	% Spawning Biomass Depletion
0.0		80.71
0.0*	0.613	48.04
-0.1	0.554	43.25
-0.2	0.501	38.91
-0.2205	0.491	38.10
-0.3	0.453	34.99
-0.4	0.410	31.50
-0.5	0.613	28.25
-0.6	0.335	25.35
-0.7	0.613	22.73
-0.8	0.274	20.36

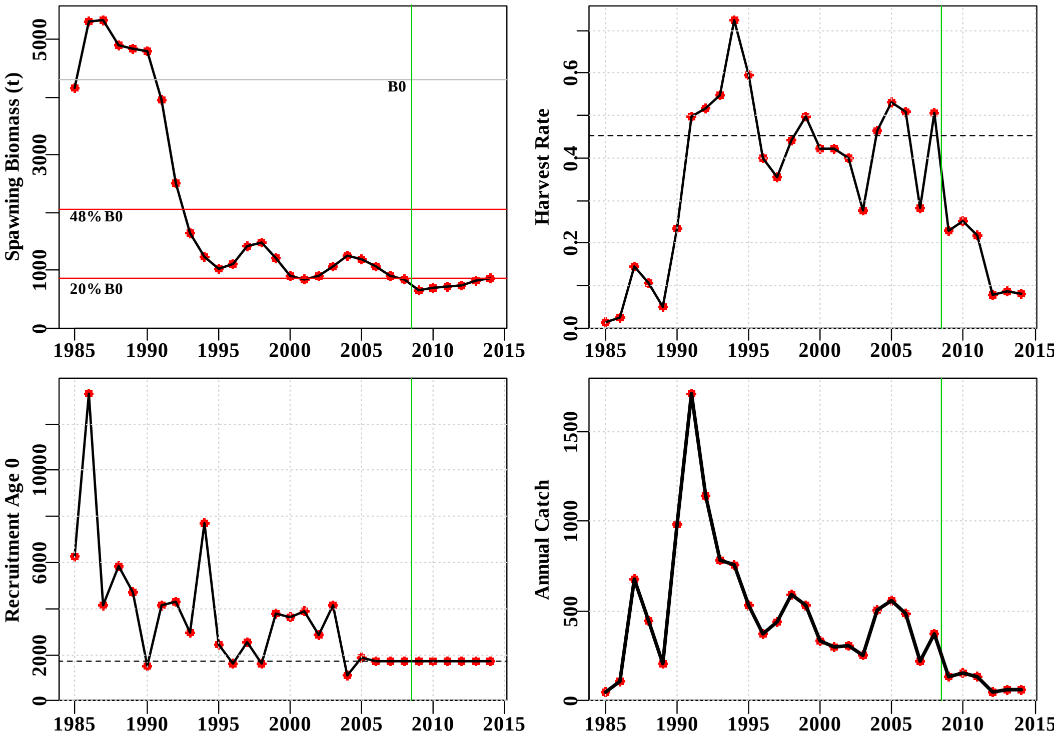

Figure 21. Predicted spawning biomass and recruitment levels for western Blue Warehou when the 2008 model is projected forward using the recent catches while setting the recruitment deviates to a constant average of -0.8. In this case the depletion level in 2008 was 19.55% while that in 2014 was 20.36%.

6.3.8 Projections with Randomized Reduced Recruitment

Constant recruitment levels provide an approximate indication of what the model dynamics imply about the stock in a deterministic manner. Instead of using deterministic projections, estimates of the relative likelihood of different outcomes can be obtained by making such projections using similar mean values for the recruitment deviates but randomly selecting the value for each year from an assumed distribution (**Figure 22**).

Two trials, using mean recruitment deviates of -0.2205 and -0.8, both with a standard deviation of 0.4, were run with 500 replicates so as to generate the quantiles around the predicted distribution of spawning biomass depletion levels in 2014 (**Figure 22**, **Figure 23**, and **Figure 24**; **Table 13** to **Table 16**).

Table 13. Quantiles of the proportional spawning biomass depletion levels for projections based on a mean recruitment deviate of -0.2205 with a standard deviation of 0.4 projected forward from 2006 – 2014 (**Figure 23**).

Quantile	2008	2009	2010	2011	2012	2013	2014
2.5%	0.193	0.156	0.177	0.205	0.227	0.259	0.286
5.0%	0.195	0.162	0.185	0.211	0.240	0.281	0.306
10.0%	0.197	0.167	0.197	0.227	0.255	0.297	0.330
50.0%	0.204	0.192	0.243	0.290	0.334	0.382	0.415
90.0%	0.216	0.238	0.316	0.378	0.435	0.483	0.519
95.0%	0.220	0.249	0.341	0.403	0.459	0.514	0.557
97.5%	0.225	0.263	0.362	0.434	0.489	0.548	0.584

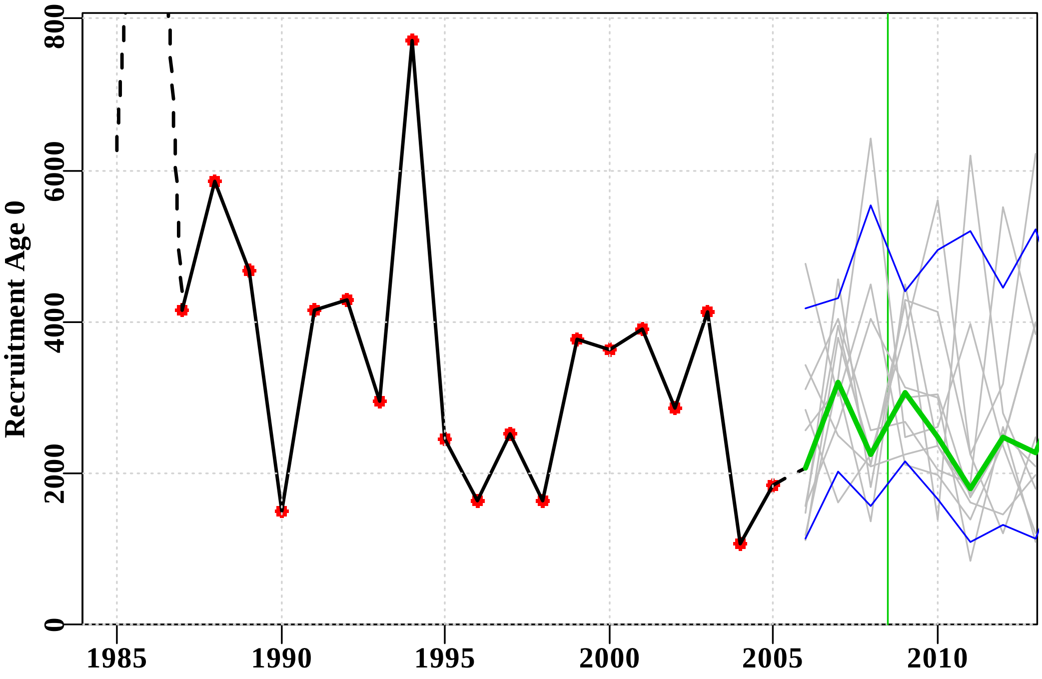

Figure 22. 10 replicate projections illustrating individual trajectories. With a mean recruitment deviate of -0.2205 and a standard deviation of 0.4 this mimics the approximate distribution of the estimated recruitment deviates, with occasional spikes but a general central tendency of approximately those estimated (in green with 90% percentiles in blue).

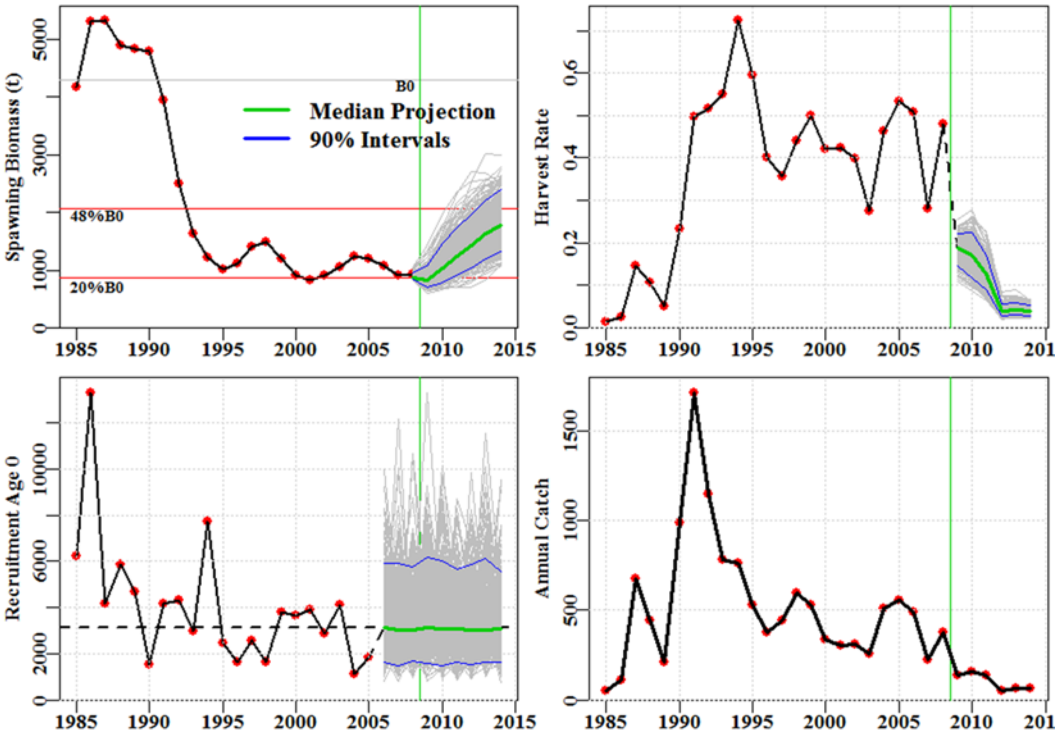

Figure 23. Predicted spawning biomass, recruitment levels, harvest rates and catches for western Blue Warehou projecting the 2008 model forward. Recruitment deviates from 2006 – 2014, had a mean of -0.2205 and a standard deviation of 0.4. The thick green lines are the median predicted values and the fine blue lines are the inner 90% distribution of the predicted variables.

Table 14. Quantiles of the annual harvest rates for projections based on a mean recruitment deviate of -0.2205 with a standard deviation of 0.4 projected forward from 2006 – 2014 (**Figure 23**). The values in 2007 are essentially unaffected by the projection but some affects appear in 2008 and onwards.

Quantile	2007	2008	2009	2010	2011	2012	2013	2014
2.5%	0.280	0.466	0.137	0.113	0.082	0.027	0.030	0.028
5.0%	0.280	0.471	0.145	0.119	0.089	0.029	0.031	0.029
10.0%	0.281	0.477	0.153	0.129	0.095	0.031	0.034	0.031
50.0%	0.281	0.494	0.188	0.170	0.125	0.041	0.043	0.039
90.0%	0.281	0.504	0.216	0.211	0.161	0.054	0.056	0.050
95.0%	0.281	0.507	0.223	0.225	0.171	0.057	0.060	0.054
97.5%	0.281	0.510	0.231	0.234	0.180	0.060	0.064	0.058

For there to have been no perceived recovery and this to have been brought about by reduced recruitment alone, the average recruitment deviate would need to decline from about -0.2205 to about -0.8. The effect of this is to reduce the amount of stock production and thereby limiting the available biomass. This in turn increases the harvest rates such that the catches, especially those from 2009 – 2011 remained too high to allow for any recovery. While the reduction in recruitment levels meant the harvest rates in 2012 – 2014 also increased, this was not sufficient to prevent a slow improvement over the last three years. This suggests that it has only been since the catches were greatly reduced from an average of ~141t across 2009 – 2011 down by 60% to ~48t across 2012 – 2014, that any recovery could have taken place.

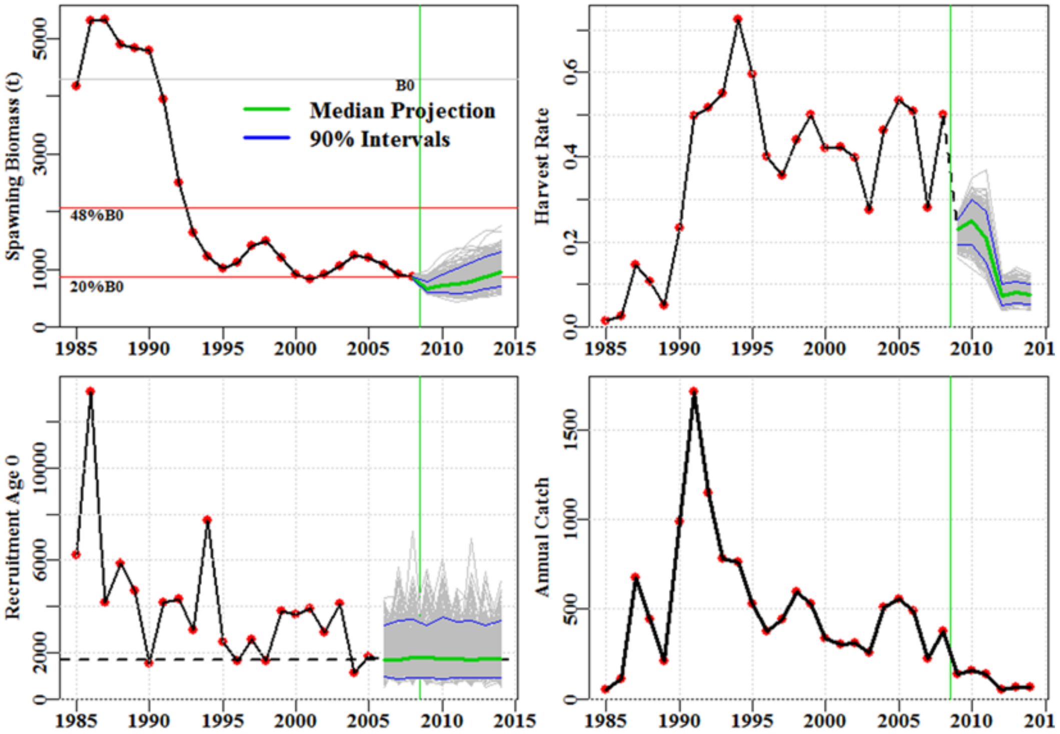

Figure 24. Predicted spawning biomass, recruitment levels, harvest rates and catches for western Blue Warehou projecting the 2008 model forward. Recruitment deviates from 2006 – 2014, had a mean of -0.8 and a standard deviation of 0.4. The thick green lines are the median predicted values and the fine blue lines are the inner 90% distribution of the predicted variables.

Table 15. Quantiles of the proportional spawning biomass depletion levels for projections based on a mean recruitment deviate of -0.8 with a standard deviation of 0.4 projected forward from 2006 – 2014 (**Figure 24**).

Quantile	2008	2009	2010	2011	2012	2013	2014
2.5%	0.190	0.138	0.132	0.127	0.130	0.144	0.155
5.0%	0.191	0.141	0.138	0.134	0.139	0.153	0.164
10.0%	0.192	0.143	0.142	0.142	0.145	0.164	0.175
50.0%	0.195	0.156	0.166	0.174	0.185	0.204	0.220
90.0%	0.201	0.177	0.203	0.225	0.239	0.263	0.279
95.0%	0.204	0.185	0.213	0.237	0.261	0.285	0.303
97.5%	0.206	0.192	0.226	0.254	0.275	0.304	0.320

In all cases the stock, in terms of median depletion level, either exhibits some recovery or stronger recovery in the last three years reflecting the much lower harvest rates predicted to occur during those years (**Table 17**). If the recorded catches are correct then the median recruitment levels would only need to decline by about half to prevent successful stock recovery (**Table 17**), although over the period 2012 – 2014, catches have declined to such a degree that recovery should now have begun even if recruitment levels have halved. Expecting rapid changes would also be a mistake as only relatively high recruitment combined with continued low catches can lead to rapid recovery; these results do, however, depend on the reported catches and estimates of discards being accurate.

Table 16. Quantiles of the annual harvest rates for projections based on a mean recruitment deviate of -0.8 with a standard deviation of 0.4 projected forward from 2006 – 2014 (**Figure 24**). The values in 2007 are essentially unaffected by the projection but some affects appear in 2008 and onwards.

Quantile	2007	2008	2009	2010	2011	2012	2013	2014
2.5%	0.281	0.491	0.186	0.180	0.141	0.049	0.054	0.050
5.0%	0.281	0.494	0.193	0.193	0.152	0.051	0.057	0.053
10.0%	0.281	0.498	0.202	0.202	0.161	0.056	0.061	0.058
50.0%	0.281	0.507	0.229	0.249	0.208	0.073	0.080	0.075
90.0%	0.281	0.512	0.247	0.290	0.259	0.094	0.101	0.094
95.0%	0.281	0.514	0.253	0.302	0.273	0.100	0.108	0.101
97.5%	0.281	0.515	0.256	0.311	0.289	0.106	0.115	0.106

Table 17. The median expected depletion level in 2014, the median recruitment levels for 2009 – 2014 relative to unfished and the average from 1987 – 2005, and the median harvest rates for two periods after 2008 across five mean recruitment deviate values.

				Harvest Rate	
Mean Deviate	Depletion 2014	Recruitment vs unfished	Recruitment vs 1987 – 2005	2009 - 2011	2012 - 2014
-0.2205	0.415	0.491	1.000	0.161	0.041
-0.4	0.336	0.409	0.834	0.180	0.050
-0.6	0.272	0.335	0.682	0.206	0.062
-0.8	0.220	0.276	0.562	0.229	0.075
-0.9	0.194	0.246	0.502	0.238	0.086

6.3.9 Projections with Increased Catches

Setting a lower level of catches as an incidental-catch-TAC for heavily depleted species has the simple objective of reducing the harvest rate to a level that will permit the stock to recover. However, currently, in trawl fisheries, this TAC is set using only the companion species approach, which identifies the likely catch level taken incidentally when fishing for the TAC for the other species typically caught in the SESSF. Such incidental catches are assumed to be sufficiently low that recovery of the depleted stock will follow.

The average catch of western Blue Warehou (**Table 4**) between 2000 – 2008 was ~372t, so the average between 2009 – 2011 of ~141t involved about a 60% reduction, and the average between 2012 – 2014 was ~58t, which was a further reduction of 60% (leading to an 85% reduction relative to the 2000 – 2008 average). The model results indicate that if recruitment had remained at the depressed level that had been occurring for the previous 20 years then the first catch reduction should have been sufficient to lead to potentially strong recovery (**Figure 23**; **Table 13**). However, it appears that, depending on the actual levels of recruitment, the catches (at least those between 2009 – 2011) were still too high despite being reduced by more than half. The second reduction that cut catches in 2012 – 2014 imply relatively low harvest rates that, even under reduced recruitment should lead to slow stock increases. Note that the stochastic projections enable the reverse analysis that suggests there is a roughly even chance of the stock declining.

While the recorded landings can be assumed to be accurate it is possible that estimates of discards are actually under-estimates. If, in fact, the stock is recovering but the TAC remains at its current relatively low level then the expectation is that capture rates would increase and hence the discard rate would also increase. This does not seem to be happening as there have been no complaints or reports from fishers of them having trouble catching unexpectedly large amounts. Quota for Blue Warehou is relatively cheap and easy to lease although nobody is wanting it despite the species still being worthwhile economically to land when caught (Simon Boag, SETFIA, pers. comm.). Nevertheless, the possibility exists that discards are still relatively rare events and are being missed by the ISMP sampling regime and are not being reported by industry members. Increased under-reported catches can be easily tested for a potential impact on stock status by artificially increasing the catches removed during the projections to determine by how much they need to increase to prevent recovery under pre-defined conditions of recruitment.

Projections were made using recruitment levels equivalent to the average over the 1987 – 2005 period (approximately 50% of unfished levels; **Table 17**) and then, to allow for a mixture of effects, recruitment levels corresponding to about a third of unfished levels. Different total catch scenarios were examined including increasing the catches in 2012 – 2014 back to those experienced in 2009 – 2011, then multiplying the original catches by 1.5 and then by 2.0 (**Table 18**).

When the recruitment levels were kept at the average for the period 1987 – 2005 (mean recruitment deviates = -0.2205) then the final depletion level remained above 35% in each case, although that for two-times the reported catches was the lowest. When recruitment was reduced to about one third of unfished levels (mean recruitment deviate = -0.6) then catches had to be doubled across the period of 2009 – 2014 for there to be only a minimal increase from 19.4% in 2008 to 22.1% in 2014 (equivalent to using the original catches with recruitment cut down to only about 27.5% of unfished (**Table 18**; **Figure 25**).

Table 18. The median spawning biomass depletion level and the median harvest rates from 2009 – 2011 and 2012 – 2014 from 500 replicates of different catch scenarios. 12-14 = 09-11 means the catches in the years 2009 – 2011 were repeated across 2012 – 2014. The standard deviation for recruitment deviates was 0.4 in all cases. Original catches are listed in **Table 4**.

	Mean Recruitment Deviates		
Catch Scenario	-0.2205	-0.6	Statistic
12-14 = 09-11	0.378	0.243	Depletion
Original x 1.5	0.384	0.249	Depletion
Original x 2.0	0.358	0.221	Depletion
12-14 = 09-12	0.161	0.205	Harvest Rate 09 - 11
Original x 1.5	0.251	0.323	Harvest Rate 09 - 11
Original x 2.0	0.353	0.462	Harvest Rate 09 - 11
12-14 = 09-13	0.106	0.160	Harvest Rate 12 - 14
Original x 1.5	0.067	0.102	Harvest Rate 12 - 14
Original x 2.0	0.098	0.158	Harvest Rate 12 - 14

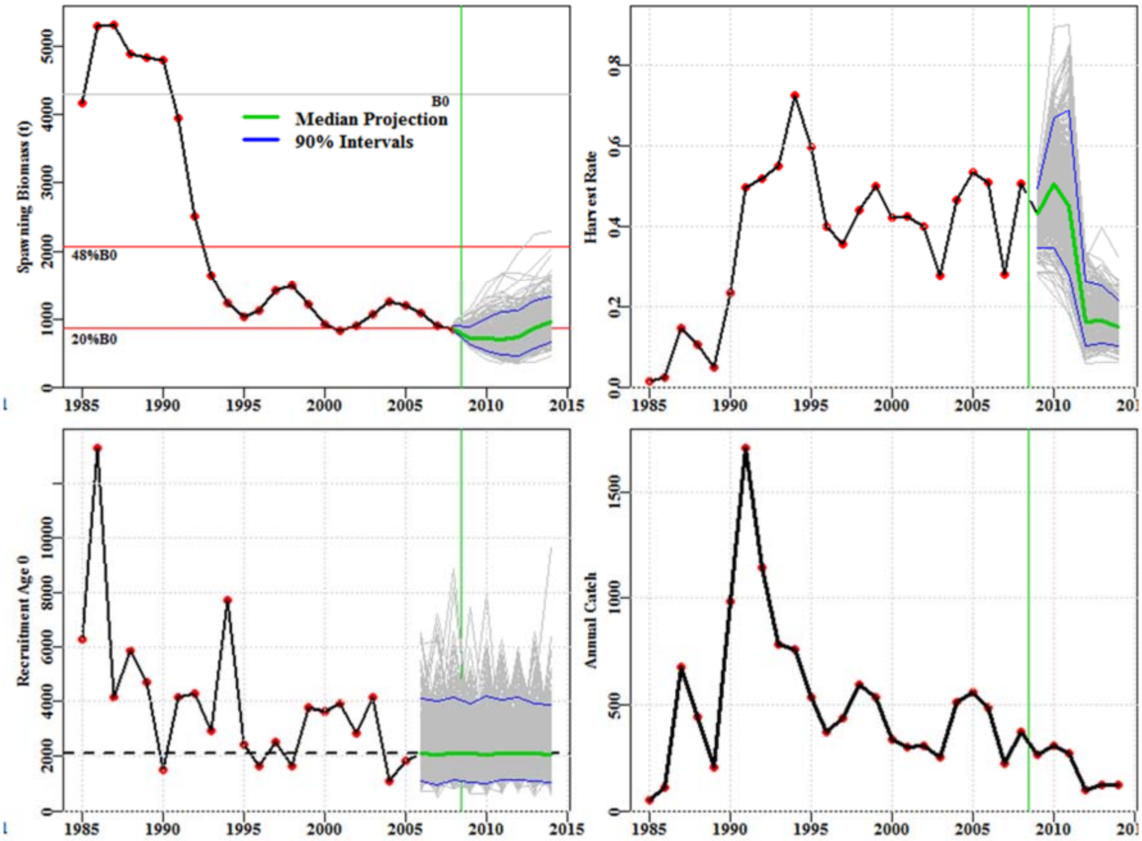

Figure 25. The predicted spawning biomass, recruitment levels, harvest rate and the catches from 1985 – 2008 with the assumed catches at two times the original catches from 2009 – 2014. The thick green lines are the medians and the fine blue lines are the 90th percentiles of the 500 replicates. Mean recruitment levels were at ~33% of unfished recruitment levels.

6.4 Avoidance of Rebuilding Species

The primary target in the gillnet-hook-and-trap fishery (GHT) is now the Gummy Shark (*Mustelus antarcticus*), although for many years (1970s – early 1990s) School Sharks were the primary target. The proportion of the total catch of School and Gummy Sharks taken by different fishing gears varies greatly, with recent changes due to the banning of gillnets in much of South Australian waters (**Figure 26**, **Figure 27**). Since the gillnet closures in South Australia, which started in 2010, the proportion of catch in the GHT taken by bottom-line has started to increase rapidly (**Table 19**, **Table 20**), although gill-nets remain the dominant method across the fishery as a whole. An examination of the log-book data for signs of targeting School Sharks would therefore need to consider both gillnets and bottom-line fishing.

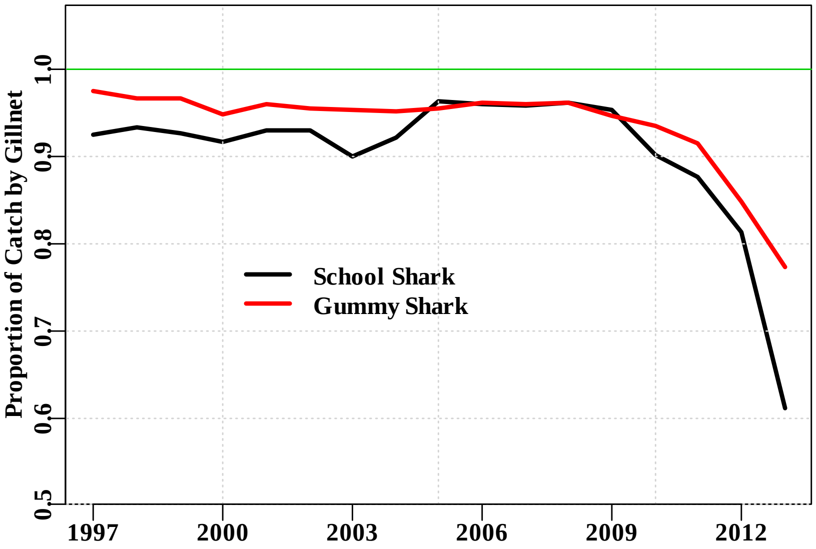

Figure 26. The proportion of the total reported catches of School and Gummy Sharks taken by gillnet (see **Table 19**). Note the y-axis starts at 0.5 rather than zero.

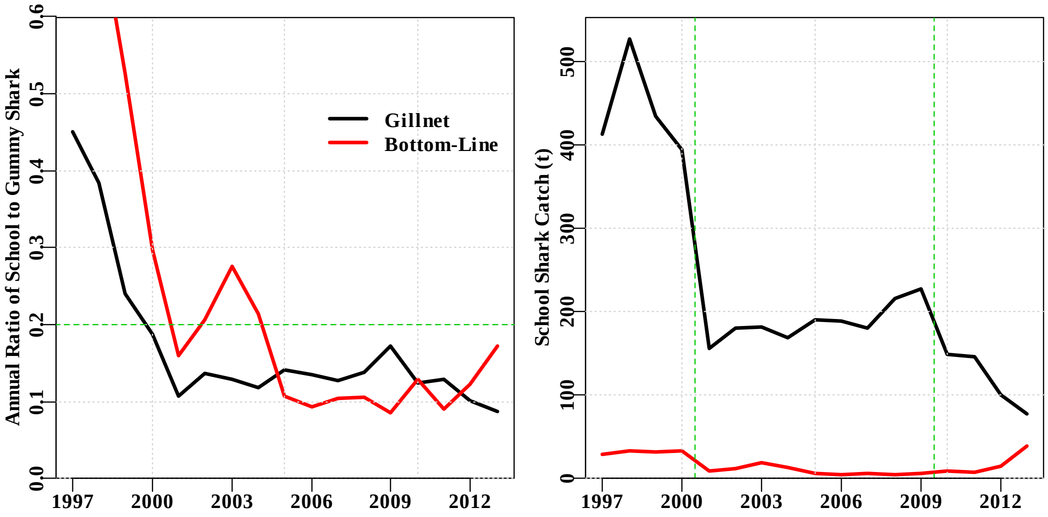

Figure 27. The ratio of School Shark to Gummy Shark catches by method (see **Table 20**) and the annual catches of School Shark reported by method. The fine green dashed lines represent a ratio of 20% School Sharks: the threshold defined as being too high (see Appendix 12, p100); and then quotas were introduced in 2001, and gillnets were banned in much of South Australia from 2010 onwards along with downward adjustment of the School Shark TAC.

Table 19. Catch by gear of School Shark and Gummy Shark. AL – auto-line, BL – bottom-line, GN – gillnet, and other includes drop-line, hand-line, trot-line, grab-all net, and unknown. %GN is the proportion of total catch across all methods taken by gillnet.

	School Shark						Gummy Shark					
Year	Other	AL	BL	GN	Total	%GN	Other	AL	BL	GN	Total	%GN
1997	4.192		28.710	413.759	447.351	0.925	0.179		19.473	918.156	941.554	0.975
1998	3.656		34.266	527.759	565.680	0.933	0.437		46.848	1375.784	1423.069	0.967
1999	2.204		32.350	434.292	468.846	0.926	1.369		61.393	1804.989	1867.751	0.966
2000	1.857		33.471	394.605	429.932	0.918	0.908		112.641	2106.693	2220.242	0.949
2001	2.084		9.509	156.652	168.245	0.931	1.118		59.390	1463.242	1523.750	0.960
2002	0.771		12.744	181.241	194.756	0.931	0.989		61.640	1320.678	1383.308	0.955
2003	1.340		18.885	182.222	202.447	0.900	0.935		68.556	1410.925	1480.416	0.953
2004	0.769		13.321	169.277	183.684	0.922	0.465		62.348	1423.668	1496.192	0.952
2005	0.396		6.511	191.107	198.244	0.964	0.530		60.697	1354.558	1417.339	0.956
2006	0.146	3.055	4.588	189.115	196.904	0.960	1.908	2.604	49.327	1392.015	1445.854	0.963
2007	0.168	1.569	5.954	180.319	188.010	0.959	0.559	1.406	57.109	1411.032	1470.106	0.960
2008	0.054	2.733	5.534	216.027	224.348	0.963	0.155	7.857	52.403	1559.189	1619.604	0.963
2009	0.671	4.458	5.926	227.743	238.798	0.954	0.215	4.680	68.941	1317.351	1391.186	0.947
2010	0.333	6.457	9.439	149.422	165.651	0.902	0.181	10.199	73.288	1205.729	1289.397	0.935
2011	0.387	11.912	8.346	146.181	166.826	0.876	0.668	10.861	92.696	1130.074	1234.299	0.916
2012	0.189	7.598	15.313	100.459	123.559	0.813	1.299	50.640	124.933	993.783	1170.654	0.849
2013	0.290	10.452	39.106	78.210	128.058	0.611	0.718	33.935	227.061	893.957	1155.670	0.774

Table 20. The ratio of School Shark to Gummy Shark reported catches from 1997 – 2013.

	Bottom-Line		Gillnet		Ratio School : Gummy	
Year	School	Gummy	School	Gummy	Bottom-Line	Gillnet
1997	28.710	19.473	413.759	918.156	1.474	0.451
1998	34.266	46.848	527.759	1375.784	0.731	0.384
1999	32.350	61.393	434.292	1804.989	0.527	0.241
2000	33.471	112.641	394.605	2106.693	0.297	0.187
2001	9.509	59.390	156.652	1463.242	0.160	0.107
2002	12.744	61.640	181.241	1320.678	0.207	0.137
2003	18.885	68.556	182.222	1410.925	0.275	0.129
2004	13.321	62.348	169.277	1423.668	0.214	0.119
2005	6.511	60.697	191.107	1354.558	0.107	0.141
2006	4.588	49.327	189.115	1392.015	0.093	0.136
2007	5.954	57.109	180.319	1411.032	0.104	0.128
2008	5.534	52.403	216.027	1559.189	0.106	0.139
2009	5.926	68.941	227.743	1317.351	0.086	0.173
2010	9.439	73.288	149.422	1205.729	0.129	0.124
2011	8.346	92.696	146.181	1130.074	0.090	0.129
2012	15.313	124.933	100.459	993.783	0.123	0.101
2013	39.106	227.061	78.210	893.957	0.172	0.087

6.4.1 School Shark Avoidance

A formal School Shark rebuilding strategy was developed in 2008 and revised in 2015 (AFMA, 2008, 2015). It aims to "…rebuild School Shark stocks to their limit reference point of 20 per cent of unfished biomass within a biologically reasonable timeframe of three generation times (66 years)." To achieve this aim various measures, including breeding area closures, fishing gear restrictions, and a minimum size limit of 450 mm have been implemented.

In addition, an important part of the strategy was to prevent "…targeted fishing for School Shark by setting total allowable catches (TACs) at the minimum incidental by-catch level and implementing a maximum rate of School Shark to Gummy Shark landings." (AFMA, 2015, p2).

The idea behind setting a ratio of the two species (20:100 School : Gummy) was that the ratio would act as a form of performance measure of targeting. As stated in the 2015 revised rebuilding strategy:

> "In 2011 AFMA implemented an additional measure to reduce instances of school shark targeting. The 20 per cent school shark to gummy shark catch ratio means an operator cannot catch an amount of school shark that exceeds 20 per cent of their gummy shark quota holdings. The ratio of school shark to gummy shark catches was limited to 20 per cent on the basis that school shark catches above this level would suggest the operator was targeting. AFMA, in conjunction with SharkRAG, will continue to review the effectiveness of the 20 per cent school shark catch ratio to determine if it meets the objectives for preventing targeted fishing for school shark whilst minimising unnecessary discarding." (AFMA, 2015, p8)

School Shark was originally the primary target of the non-trawl fishery and relatively large catches (between 1200 – 1500t per year) were taken through the 1980s. However, concerns for the sustainability of the fishery began with a formal management plan being introduced in 1988, which attempted to control effort by reducing allowable net lengths (input controls prior to the quota system being introduced). Despite further cuts to net lengths, catches continued to decline so that in 1997 the maximum gillnet mesh size was reduced to no more than 6.5" (165mm), with the objective of reducing or preventing the targeting of School Sharks, which is best done with larger mesh sizes. Annual catches reduced accordingly down to between 400 – 500 t (**Table 20**). Both Gummy and School Sharks were brought into the quota management system in 2001 partly with the objective of reducing School Shark catches down to incidental by-catch only (AFMA, 2015). The TAC for School Sharks started at 291t but was reduced to 240t by 2007. Following a dip of the TAC down to 150 t in 2012 it has been 215 t from 2013 as this was the level now considered to be the expected unavoidable incidental by-catch from the Gummy Shark fishery (AFMA, 2015). At the same time catches have been about 200 t per year and this is considered to be well within the surplus production and should allow the stock to recover (**Figure 28**).

Following reports that some targeting was still occurring, in 2010, analyses were undertaken to examine incidental catches in more detail. This led to a simple algorithmic approach to the data analysis required which has now been developed into the recommended approach described here (**Figure 29**). It should be noted that by using log-book data it is not possible to prove that targeting occurred rather than avoidance, but it is possible to identify whether some vessels are failing to avoid School Sharks successfully.

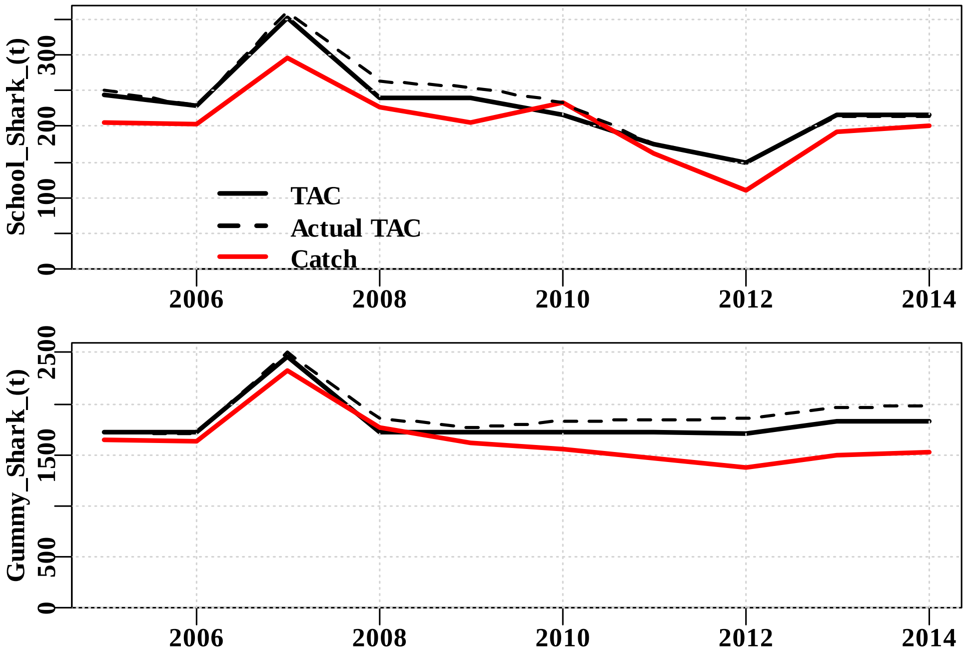

Figure 28. The agreed TAC, the Actual TAC (which includes under- and over-catch provisions), and the actual landings. The apparent increase in 2007 reflects the 16 month season used during the transition from calendar year (Jan – Dec) to a fishing year (May – April). From 2008 the year represents the fishing season, so 2014 is for 2014/2015. Discards are not included but from 2011 – 2013 were approximately 9, 12, and 14% for School Sharks and 6, 3, and 3% for Gummy Sharks.

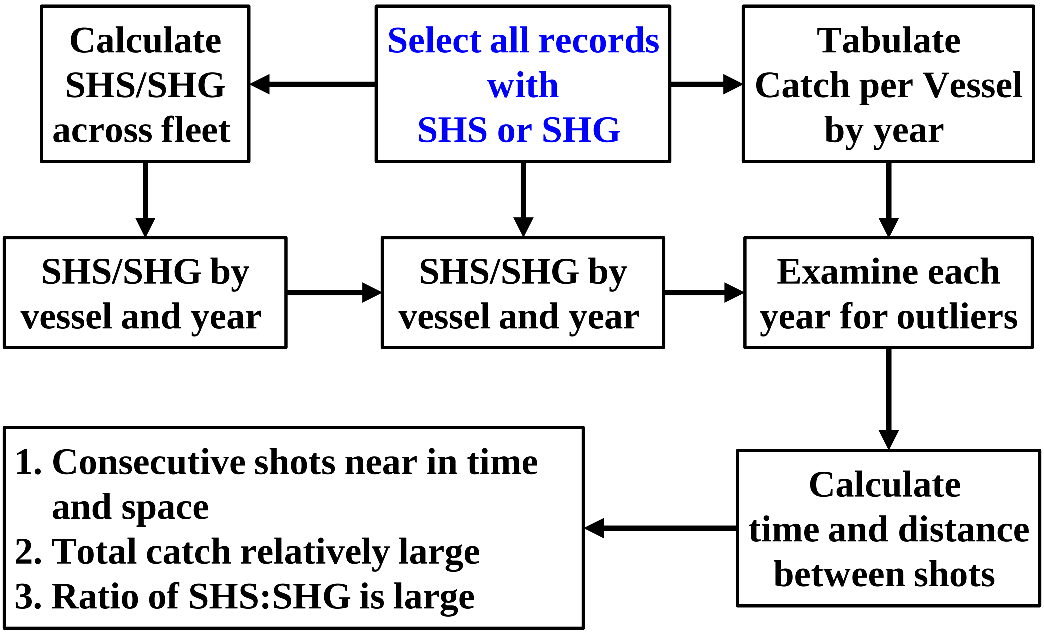

Figure 29. A schematic sequence of steps used to evaluate the fishing behaviour of a fleet in any particular period with respect to the targeting or avoidance of School Sharks. SHS = School Shark and SHG = Gummy Shark.

Quotas were introduced for Gummy and School Sharks in 2001, and the TAC for Gummy Sharks was reduced from 2159t to about 1800t in 2002 and this was attributed to trying to increase catch rates in the Gummy Shark fishery as a means of increasing profitability. Also, at least part of the objective behind this TAC change was to eventually reduce Gummy Shark effort and thereby reduce any by-catch of School Sharks. In the Shark RAG, shark fishers stated that they wanting to avoid any further reduction in the Gummy Shark TAC and so generally, after 2010, the industry improved their avoidance of School Sharks (**Figure 30**; **Table 21**), although possibly at a cost of missing out on some Gummy Shark catches. The proportion of the total School Shark catch by gillnet in any year up to 2009 averaged 72.4% for vessels catching > 5t, but declined rapidly from 2010 – 2013 (**Figure 30**; **Table 21**).

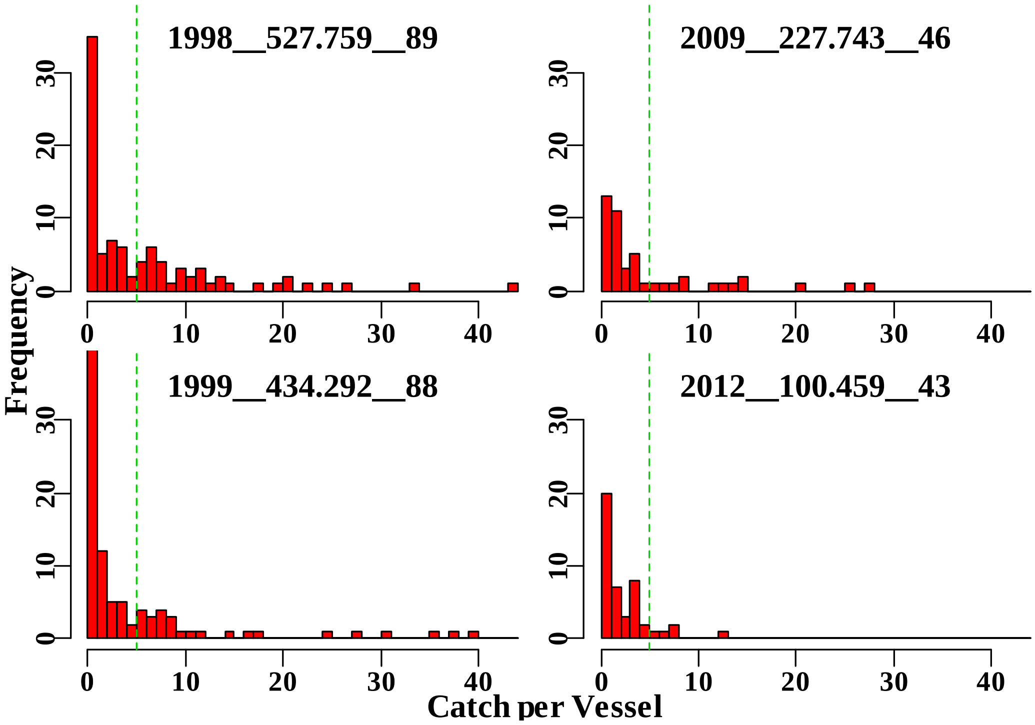

Figure 30. Typical frequency distributions of catch of School Shark per gillnet vessel, in tonnes, from 1998 and 1999 compared with those from 2009 and 2012. The title number in each case is the year plus the total catch by gillnet, while the final integer is the number of vessels reporting catches. The fine green lines denote 5 tonnes, to ease visual comparisons. Active avoidance of School Sharks was greatly encouraged from 2010.

In 2010 there did not appear to be any regulatory penalties for those that do not avoid School Sharks, nevertheless, peer pressure among industry members has been very effective at maintaining efforts to avoid their capture. Now an array of conditions-of-operation have been imposed upon operators (see Appendix 12, p100) which act to limit the ratio of School Sharks to Gummy Sharks but also define catch constraints on individual fishers, which derived from analyses of log-books such as conducted here, plus knowledge of quota holdings.

To explore whether or not there continue to be any signs of targeting there are two sequential and complementary approaches when using the log-book data to search for evidence suggesting that targeting is occurring. The first being a simple examination of catch per vessel to determine whether any particular vessel is catching a relatively large proportion of the total School Shark catch, while the second examines the ratio of School Shark to Gummy Shark catches for individual vessels through the year (**Figure 29**).

Table 21. The number of vessels reporting School Shark catches from 1997 – 2013, plus the number reporting catches > 5 t, and the proportion of the total caught made up by those vessels catching > 5t.

Year	All Vessels	Vessel > 5t	Proportion > 5t
1997	88	20	0.829
1998	89	36	0.877
1999	88	26	0.848
2000	76	24	0.872
2001	76	10	0.604
2002	74	9	0.551
2003	80	10	0.582
2004	78	9	0.601
2005	63	14	0.714
2006	58	12	0.648
2007	46	10	0.683
2008	45	15	0.826
2009	46	13	0.771
2010	48	9	0.518
2011	47	8	0.512
2012	43	5	0.394
2013	40	2	0.181

If particular vessels stand out from the majority as catching relatively large amounts, or having a relatively high ratio of the two sharks then closer attention can be paid to whether or not any larger shots were consecutive in time or close to each other spatially, or both (**Figure 29**). If they are separated either temporally or spatially then the recorded captures may have occurred by chance. Even if they occur close to one another this does not demonstrate targeting, although it can demonstrate a failure to avoid School Sharks (**Figure 31**, **Figure 32**, and **Figure 33**).

If there are very large catches these can be further explored by considering how far apart they are in time or spatially (**Figure 32** and **Figure 33**). **Figure 32** was presented to the Shark RAG in 2012 (Haddon, 2012) as a demonstration of such a detailed analysis of the data from a single vessel (one which had taken 10% of all School Sharks taken by gillnet that year – details were not published in the annual stock assessment reports, e.g. Tuck, 2014, for reasons of confidentiality relating to single vessels). In fact, on sites where large catches of School Shark were taken there was no evidence of shooting-back on the same or following days. Invariably the operator moved distances greater than 0.5 degree (latitude or longitude) and only returned closer to the area of larger catches after about a week had passed (**Figure 33**).

Similar analyses for the Bottom-Line method also indicate operators moving on if they catch elevated catches of School Shark (**Figure 34**).

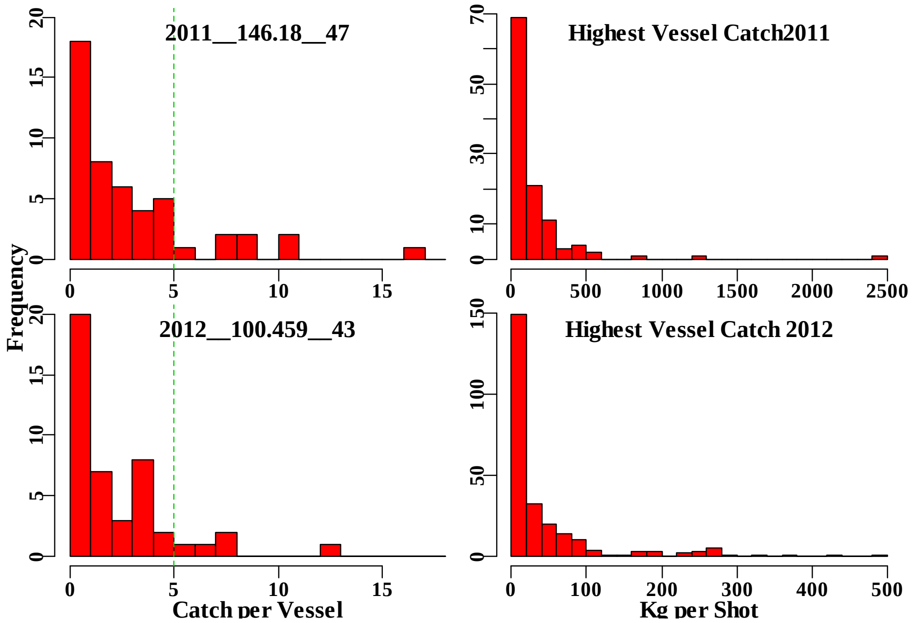

Figure 31. The catch across all gillnet vessels in 2011 and 2012 compared with the catch per shot for the vessel with the largest catch in each year. In 2011, there were a few larger shots but these were well separated in time and space, and most of their shots were < 300kg; the vessel catching 16.7t is featured in the top right plot here and also in **Figure 32**. In 2012 the vessel, which caught just over 12 tonnes was very actively fishing but generally caught less than 100kg School Shark.

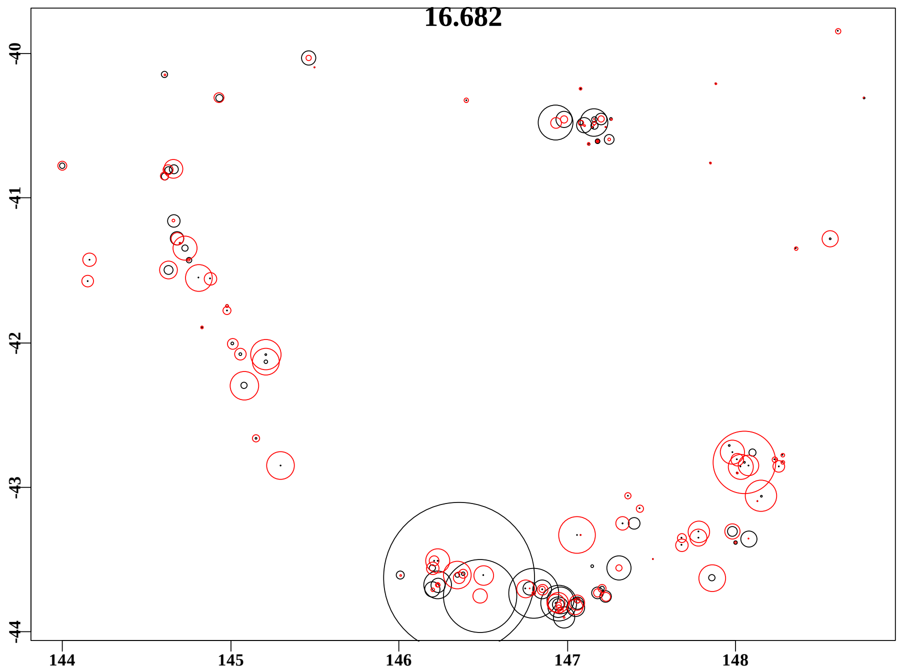

Figure 32. The schematic locations and relative size of School Shark catches of an individual vessel in 2011. The total catch was 16.7 t of School Shark (see the top two plots in **Figure 31** for catch per vessel in 2011, and the separate catches for the vessel featured here). None of the aggregations of catches were shot in close proximity in time, so there was no ‘shooting-back’ where a specific location where a large catch is taken is quickly repeated.

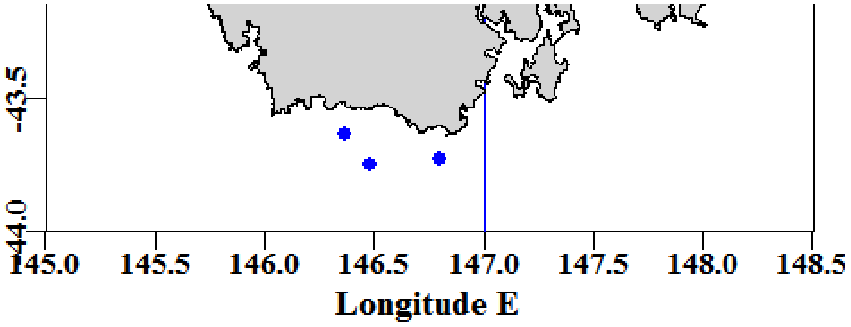

Figure 33. Schematic map of southern Tasmania. The three largest shots from the vessel with the highest School Shark catch in 2011 (**Figure 32**) are marked in blue. The two points furthest apart were one day apart, while the third occurred 10 days later.

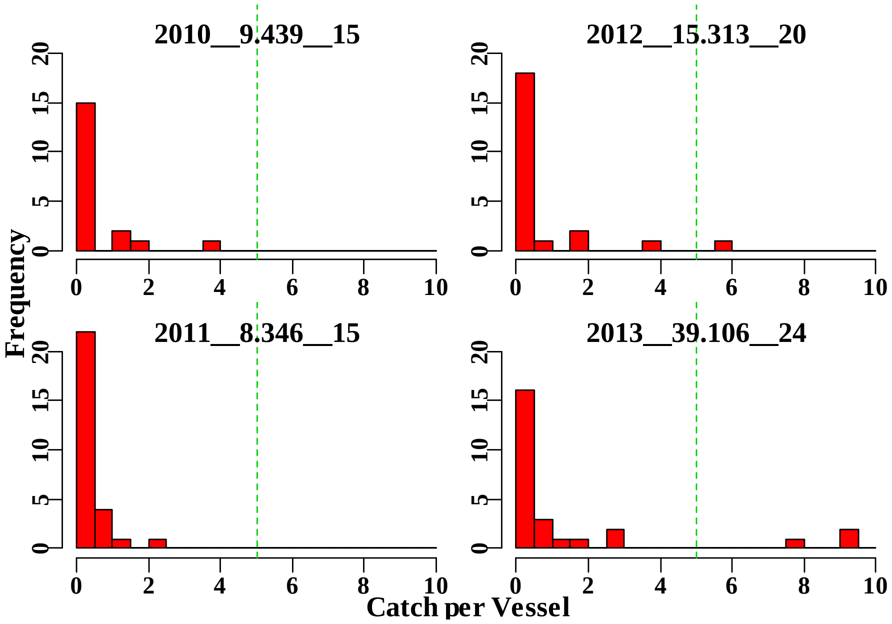

Figure 34. The catch per vessel for bottom-line vessels since they have returned to popularity. Note the increase in the number of vessels and catches in 2012. Examining the individual catches of the highest catching vessel in 2013 exhibits them moving their operations by about 0.5 degree each of the four times they caught more than 500kg.

Currently there is little evidence to suggest that any fisher is specifically targeting School Sharks. The conditions to operate described in Appendix 12, appear to be very effective. Similar conditions have not yet been developed for eastern Gemfish or Blue Warehou.

6.5 Application to Data-Poor Species

The third and fourth objectives state:

Determine whether any of the methods developed under objectives 1 and 2 can apply to relatively data poor species; develop guidelines for application to species for which there is only catch data.
and
Assess the feasibility of extending the methodology above in objective 1 to develop a practical and workable methodology to estimate acceptable capture limits for rare and TEP species.

6.5.1 Data-Poor Species

Species or fisheries which can be considered data-poor in Australia cover a broad spectrum of data availability. Within the SESSF the basic data-poor method is currently ensconced in the Tier 4 harvest strategy, which still requires accurate catches and catch rates so as to make comparisons between the recent average catch rates and some selected target or reference catch rate from the fisheries history (**Figure 35**). With no reference to the underlying population dynamics this is a purely empirical harvest strategy. However, the availability of both accurate catch data in conjunction with a viable index of relative abundance would not be considered data-poor in many other countries (Geromont and Butterworth, 2015). Nevertheless, in Australia, there remain many species and fisheries for which there may only be catch data available and these can justifiably be termed data-poor.

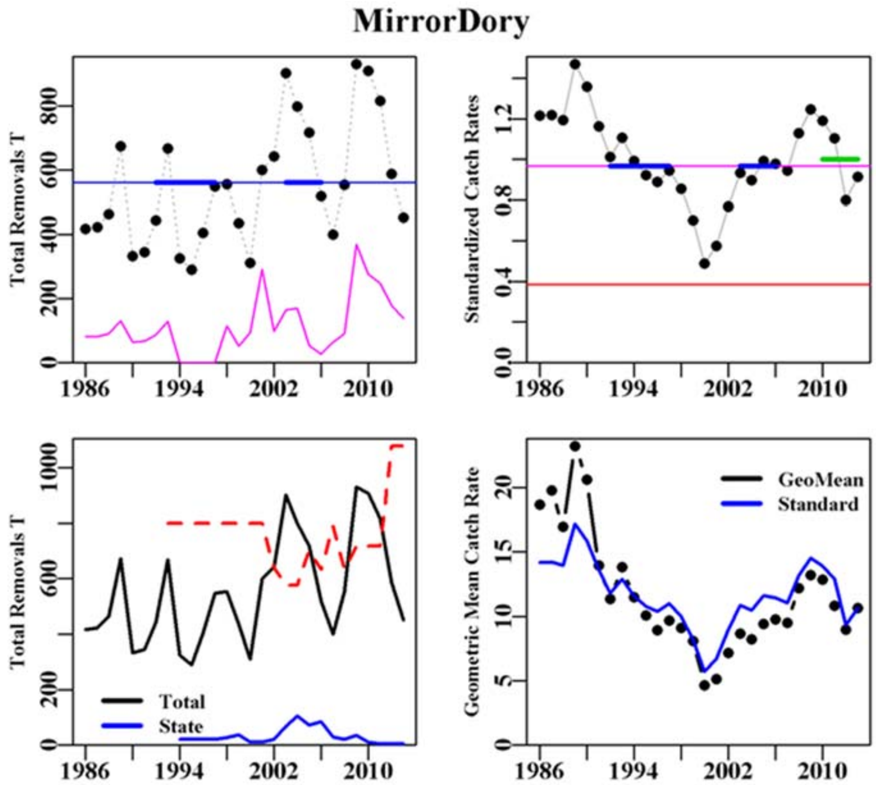

Figure 35. Top left is the total removals, the pink line is discards and the fine blue line is the target catch. Thickened lines represents the reference period for catches, catch rates, and the recent average catch rate. After figure 15.2 in Haddon (2015e).

6.5.2 Data-Poor Harvest Strategies

Detecting whether a truly data-poor species is below even a proxy for the limit reference point would be intrinsically difficult, depending on the form of any harvest control rules that might be developed. In some cases (e.g. the Commonwealth western deepwater trawl fishery) where there can be basket species that collect together different species of the same type (**Figure 36**), and there are only catch triggers that determine increases in required information before the fishery can expand further, the assumption is made that the catch triggers are set at levels which will ensure the stock concerned will remain above the limit reference point (or proxy). The ecological risk assessment applied to all species is currently the only assessment used with very many species, especially the very low value and very data-poor species. Before any of the guidelines suggested here could be applied to data-poor species at least some form of limit reference point would need to be defined in a defensible manner.

Figure 36. The catch of three species of scampi (M*etanephrops velutinus*, *M. australiensis* and *M. boschmai*), treated as a 'basket' species in the Western Deepwater Trawl Fishery. No separation by species is made and the fishery is geographically extensive (Larcombe and Begg, 2008). While there is catch and CPUE data available it is for a mixture of species which are known to have somewhat different geographical distributions, so the catches and CPUE are intrinsically misleading.

Fortunately, both here in Australia and internationally (Berkson and Thorson, 2015; Geromont and Butterworth, 2015, 2015b; Carruthers *et al.*, 2014, 2015; Haddon *et al.*, 2015) there have been recent initiatives to test and adopt data-poor stock assessment methods and their associated harvest strategies.

Of the new data-poor assessment methods only the model-assisted methods, that use only catch data but assume a model describes the underlying dynamics adequately, may be suitable for a consideration of whether they are suitable to examine the potential risks of different management actions (Haddon *et al.*, 2015). Although there are other empirical harvest strategies which may be more suitable for cases that involve 'basket species'.

One advantage of these investigations into data-poor methods is that they open the way to producing defensible methods or developing at least limit reference points and possibly target reference points for data-poor species. If this occurs then there would be the possibility of determining whether a data-poor species has become severely depleted. However, not surprisingly, all of the data-poor methods developed to date have very uncertain outputs, which means that detecting when a data-poor species has breached even a formal LRP, would be difficult to do in a convincing manner. Of course policy decisions could be made concerning what could be considered as a significant depletion level for such species, once particular data-poor methods and harvest strategies had been adopted.

7 Discussion

7.1 Guidelines for Setting Incidental-Catch TACs

7.1.1 Companion Species

When the Commonwealth harvest strategy policy (HSP) was first introduced in 2007 it was recognized that there were already some severely depleted species. A key problem with such species is that each harvest control rule within each harvest strategy implies an RBC of zero if the assessment estimates that the stock has fallen below the limit reference point. In mixed fisheries reducing catches to zero is impossible without compromising the catches of other healthy stocks. To avoid this and to avoid discarding of potentially valuable incidentally caught species, some means of setting incidental-catch only TACs was required as part of the rebuilding strategy. However, in 2007 there were no agreed rules or methods for setting the "by-catch TACs" (Smith *et al*., 2008) or the currently more accepted terminology of "incidental-catch TACs".

At the outset of the HSP's introduction it was known that some species, including Orange Roughy and eastern Gemfish were very much depleted below their original unfished state. For example, relatively large catches of eastern Gemfish were taken through the mid-1980s such that catches were greatly reduced by 1991 and the non-spawning run fishery CPUE had declined by 1996 with no persistent signs of recovery since (**Figure 37**).

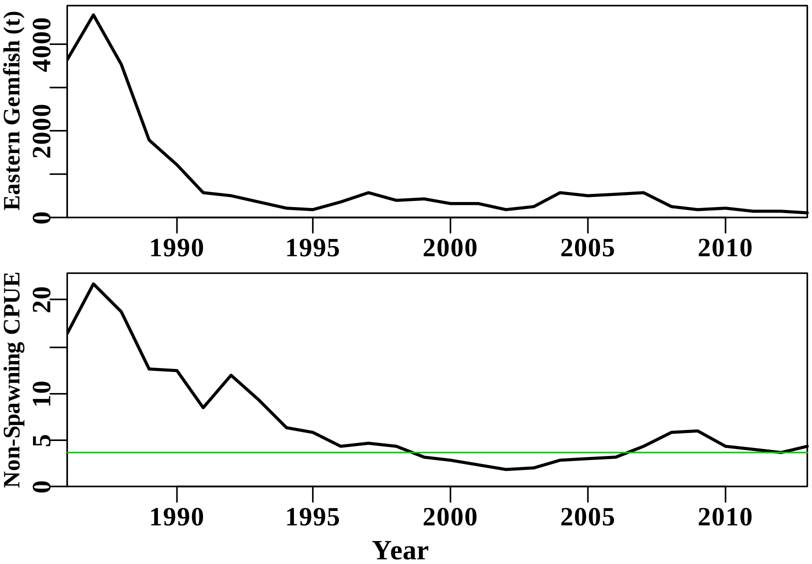

Figure 37. Eastern Gemfish total catches and the non-spawning fishery standardized CPUE (kg/hr) modified from Sporcic and Haddon (2015). The green line is the average CPUE from 1996 – 2013.

The lack of any standard methods for setting TACs for severely depleted species meant that initially such incidental-catch TACs were set in a relatively *ad hoc* manner, but very quickly the idea of using the companion species analysis was accepted. This began development in 1994 (Klaer and Tilzey, 1994), was revised in 2008 (Klaer and Smith, 2008) to complement the introduction of the HSP, and was formally described in 2012

(Klaer and Smith, 2012). The notion of using the companion species approach to set incidental-catch TACs in mixed fisheries like the SESSF is attractive because it automatically takes into account the multi-species nature of the fishery. The companion species approach defined targeted catches within {0.5° × 50m × month × time-of-day} strata in terms of the most valuable species (average price x weight) taken within each operational record of effort made within each stratum. In simple terms, using this definition, targeted and incidental catches were estimated for each record and summed for each stratum, and the sum of all incidental catches across strata was used to provide an estimate of the incidental catch TAC.

This approach led to some heated discussions in resource assessment group (RAG) meetings because of the assumption that any 'targeting' implied an intention-to-catch, which for incidental-catch-only species was sometimes loudly denied by individual fishers. Arguments over intent-to-catch or otherwise or whether literal targeting of a species occurred were not constructive because the operational definition of 'targeting' used in the approach was what actually mattered rather than intent or otherwise of the fishers. It was the operational definition that effectively determined the incidental-catch TAC. If there had to be arguments in the RAGs they would perhaps have been more constructive if focused on whether the operational definition misclassified any catches as targeted when they should have been classified as incidental because the relative-value argument became biased through changes in value through time.

The advantages of the companion species approach are that it is almost guaranteed to provide an estimate of unavoidable catch for managers to use in their rebuilding strategy (**Table 2**), At the same time, it used mainly fishery-dependent data and was relatively simple in conception (although some of its assumptions were more complex). However, it also has a number of disadvantages beyond its sometimes controversial definition of targeting (**Table 2**). Some of the problems are merely difficulties relating to implementation. Thus, for example, pricing data ought to be collected routinely and when it is collected it should be made more freely available for use in analyses such as these. In addition, the extent of missing data fields can be reduced by improving reporting or imputing missing data values from related records in the catch and effort logbook database.

7.1.2 Significant Problems with the Companion Species Analysis

A less easily solved problem is that the companion species approach to setting incidental-catch TACs requires some relatively strong assumptions about how different scalefish species associate (or not) and how fishers behave. These assumptions also influence two other potential issues which are (1) that any underlying population dynamics driving the relative abundance of different species is ignored, (2) as is the variation inherent in any fisheries logbook data, especially the species mix data. The most important issue, however, is the assumption that fishers have expectations or can predict what they might catch in any given {0.5° × 50m × month × time-of-day} stratum.

It is certainly true that fishers can develop generalized expectations stemming from years of experience in the fishery. Further, some species are more predictable than others. For example there are areas, times of year, and depths known to be favoured in order to catch species such as Blue Warehou, eastern Gemfish, and Pink Ling. With Pink Ling there are four very small areas that have been seasonally or voluntarily closed when it was desired to limit their catches (**Figure 38**). The basis for these seasonal closures were that Pink Ling was considered to be commonly caught and more easily caught in these spots. So such predictability is supported by industry inspired management practices. On the other hand, the notion that Pink Ling catches are constrained by closing these small areas has never been formally tested.

In opposition to this notion of predictability was a trawl survey conducted in 2005 to aid the Blue Warehou stock assessment (Haddon, 2007a, b), which failed to be useful because one of the two carefully selected strata, well known by industry for Blue Warehou catches at the survey's time of year, led to only very small or no catches during the survey period. This illustrates that expectations can be held very precisely for where and when to catch a particular species but that does not mean they will always be met.

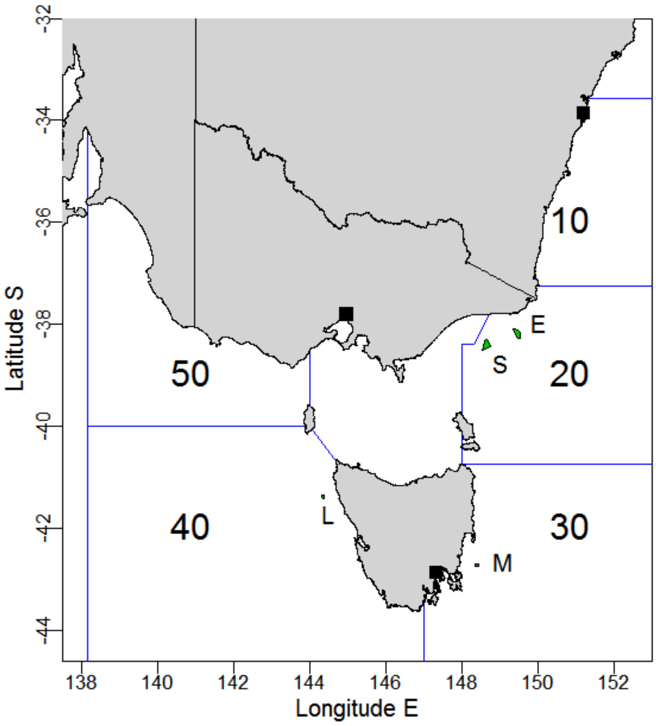

Figure 38. Schematic map of SESSF reporting blocks 10 – 50, with the fine blue lines representing block boundaries. The locations of Sydney, Melbourne, and Hobart are indicated by black squares from top to bottom. The four seasonal closures, in green, aimed at reducing catches of Pink Ling are M, Maria Island; S, Seiners Horseshoe; E, Everard Horseshoe, and L, the Ling Hole.

The analyses conducted in this project illustrate that large amounts of variation in species composition can occur over an array of different geographical scales used in the stratum definitions used by the companions species approach (0.5° cell, month, 50m depth category, and time of day). The depth distribution of a species appeared to provide more guidance concerning where a species might be found (or not found) as did time of day, although even records from these levels of strata exhibited high levels of species composition and relative abundance (**Figure 10** to **Figure 14**; **Table 9** to **Table 11**). Despite exhibiting an element of predictability, the species composition and relative abundance in different instances of stratum factors such as which month, or which 50m depth class, or even which 0.5° cell, were associated with high degrees of variation, which extended to which species were present, when they were present, and in what relative quantities.

If the assumption is inaccurate that fishers have a good idea of what species can be expected to be taken in a particular month, in a particular area, in a particular depth, at a particular time of day, is inaccurate, then the catches estimated in those records to have been incidental and those estimated to have been targeted are also likely to be inaccurate. This issue reflects the difference between the notion of species associating with each other or merely co-occurring in relation to their actual responses to environmental conditions.

Before rejecting this analytical approach for any particular species, the assumption about the predictability of catches would need to be checked or tested for each species concerned. In addition, currently the method has only been applied in the SESSF trawl fishery and those managed using a Tier 1 harvest strategy. If a new species became severely depleted that did not fit into that group (perhaps in the gillnet, hook, and trap fishery) then the methodology would need to be extended to any such new fishing methods. Currently, the incidental-catch TAC for School Shark has been set through the use of deterministic projections of the Tier 1 stock assessment model (Thomson, 2013).

The companion species approach to setting an incidental-catch TAC remains and could be used if the economic data are available and the assumption that catches of each species are sufficiently predictable as to make the analysis valid. However, the analyses conducted here suggest that before the method is applied to any particular species the assumption of predictability at a {0.5° × 50m × month × time-of-day} stratum level at least be tested.

7.1.3 Alternatives to Companion Species

In the section on risk assessments for rebuilding species (section 7.3, p80) the use of stochastic projections of stock assessment model outcomes is discussed with respect to testing whether a reduction in recruitment levels or inaccuracies in recorded catches could be at least consistent with, or even a sufficient explanation for a failure of a depleted species to rebuild in the expected time-frame put into a rebuilding strategy.

Such stochastic projections can also be used, without altering the estimated stock productivity, to test the potential outcomes of different maximum constant catches so that an array of catch versus predicted rebuild times can be presented to managers for selection. Previously, with School Sharks (Thomson, 2013), deterministic projections were used to identify viable catch limits along with their predicted rebuild times. While deterministic projections can sometimes be sufficient for management purposes, the use of stochastic variation applied, at least, to future recruitment levels enables the inclusion of estimates of how likely different outcomes of the rebuilding strategy would be given different incidental-catch TAC levels. Like the current companion species approach, this would currently only be possible with those species for which Tier 1 formal stock assessments were available.

Stochastic projections can have a number of uses beyond estimating the maximum catch levels that would still permit rebuilding with an agreed level of likelihood. Blue Warehou is a species which is exhibiting no signs of recovery. The use of projections for the

Tier 1 stock assessment model was used to test under what conditions current catches of Blue Warehou (not just the incidental-catch TAC, which, as intended, is not fully taken) should rebuilding occur and under what conditions would it not occur. The materials illustrated in the results (section 6.3, p51 - 59) were presented to the Shelf RAG on 23 September 2015 (Haddon, 2015c). The results indicate (see later) that if recruitment had continued at the average level predicted by the stock assessment model to have occurred from 1987 – 2005, then significant and noticeable rebuilding should have occurred. Any failure to rebuild is not thought to have been due to under-reported catches or discards as any such over-catching would have to occur far more than is plausible.

Stochastic projections could thus be used to predict under what conditions a failure to rebuild might occur and it suggests that recruitment would need to be depressed to the lowest levels predicted to have occurred from 1987 – 2005; although, of course, it could not suggest why recruitment levels may have declined to such levels. Such projections cannot demonstrate that a particular mechanism is the cause behind any set of observations (such as an apparent failure to recover). The projections can, however, illustrate the implications of different modelled scenarios and determine whether the model predictions are consistent or inconsistent with the observations. Consistency with observations can suggest a sufficient cause but cannot demonstrate that a mechanism was necessary for observations to have occurred.

For a newly depleted species with a Tier 1 assessment (e.g. Redfish, AFMA 2015c) it would be completely plausible to set up a series of stochastic projections using an array of plausible scenarios (sourced from the RAG and other stakeholders) to determine what levels of incidental-catch would lead to rebuilding under what expected time-frames, and with what likelihood. If there were concerns over other species often caught with the depleted species then either the full companion species analysis could be conducted or even just a characterization of the relative catches of different species in very recent years to determine whether technical interactions between species can be expected to occur. What this means is that if effort is reduced on a depleted species will fishers be unable to catch their full allocation of other species at the same time?

In the absence of the actual catches that will be taken, however, such analyses could be misleading. If the 5:1 ratio of Gummy Shark to School Shark was truly the case then one might expect that the maximum catch of Gummy Shark could only be 5 x 215 t (1075 t), however, with the actual catches it is clear that there is good success in avoidance of School Sharks, allowing larger catches of Gummy Sharks to be caught (**Table 19**).

7.2 Avoidance of Rebuilding Species

There are difficulties in managing depleted species that are components of fisheries for a complex mix of species. The difficulties cover the range of the concepts of depletion and recovery, the effectiveness of management actions for achieving recovery, the details of implementing management controls, and the problems relating to the determination of stock status once a species is declared depleted. Each of these areas raises issues that relate to policy decisions although currently available policy with respect to rebuilding is both very specific and unfortunately vague. Thus, the policy can be very prescriptive about things like recovery times. For example, in the Guidelines for Implementing the HSP, it states:

"*For a stock below B_{LIM} a rebuilding strategy will be developed to rebuild the stock to B_{TARG}. Once such a stock is above B_{LIM} it may be appropriate for targeted fishing to recommence in-line with the stock rebuilding strategy and HS.*" (DAFF, 2007, p 24).

But then there are vague comments with respect to whether or not the rebuilding strategy should give way to the usual harvest control rule for the species concerned. Also, in terms of timeframes for rebuilding the *Guidelines* state:

"Typically recovery times are defined as the minimum of 1) the mean generation time plus ten years, or 2) three times the mean generation time." (DAFF, 2007, p. 44).

However, there was no guidance given for situations where there is a failure to recover. One unusual aspect related to the declaration of an incidental-catch only TAC instead of a simple zero TAC, is that, unless there are regulations or conditions of operation to the contrary, it is not illegal to accumulate available quota for a depleted incidental-catch only species, and then target this species; despite this being completely against the intent of the harvest strategy policy.

When such catch restrictions were first put in place for the species depleted prior to the introduction of the HSP, such 'accumulation of quota to target' behaviour, whether it occurred in reality or not, led to conflict in the Shark RAG in 2010 and 2011 over School Shark catches. The incidental-catch TAC for School Shark is one of the few fished species within the SESSF whose TAC is regularly taken almost in its entirety (**Figure 15**). It is also the case that the Gummy Shark catch appears to have been reduced at least partly as a result of fishing behaviour aimed at avoiding School Sharks. By examining records from individual vessels (e.g. see **Figure 30** to **Figure 34**, and Haddon, 2012), it was possible to identify whether there were any particular vessels taking either a high level of School Sharks or that had a unexpectedly high ratio of School Sharks to Gummy Sharks in their reported catches. However, by 2012 a combination of peer pressure and the application of conditions to operate (see Section 12, p 100) led to catches of School Sharks being greatly reduced and even the vessel that took the maximum catch in 2012 had no large catches followed immediately by other large catches. In addition, shot locations which led to relatively large catches were avoided for numbers of days in each case (in effect an informal move-on rule).

All vessels in the year 2012 and 2013, irrespective of how much they caught in total through the year, caught most of their total catch in individual shots of less than 300kg. Now there are trip limits and other constraints (see Section 12, p 100) but these could only be developed through the use of such detailed vessel by vessel analyses. There are currently no guidelines for how to operate if School Sharks were to begin to recover in any serious fashion. What would be expected is that discarding would begin to increase and obtaining quota to cover even the restricted catches allowed in the operating conditions would begin to become more difficult as everyone began to have more trouble avoiding School Sharks.

7.2.1 The Concept of Depletion and Recovery

The schooling, and sometimes seasonal, behaviour and consequent relative ease of targeting such species as School Shark, Blue Warehou, and eastern Gemfish, can give the false impression that because a species can sometimes be highly available to be caught, the stock must be large and secure. The intuition should really be that the species concerned is more likely to be vulnerable to over-fishing and depletion simply because at times it is easily caught. Once the schooling or migratory behaviour of a species along a coastline is known, then this behaviour also makes it relatively simple for an operator to go against the intent of the HSP and a rebuilding strategy by targeting a depleted species once they have sufficient quota to do so.

The reduction in the quota available as a result of introducing an incidental-catch TAC may not be sufficient incentive to prevent some opportunistic targeting. The operation of the current quota system actually provides incentives to do the wrong thing with respect to rebuilding strategies. If someone owns quota rights, simply not catching it does not mean they then do not need to pay levies on that quota. This means the incentive is there to encourage fishers to go out and at least catch the quota they own, even if they do not lease in more.

The catch and effort log-book data can only be used to explore relative catch levels rather than trying to consider absolute amounts or even ratios. Operators now need to hold five times more Gummy Shark quota (both caught and uncaught) than the amount of School Shark that the operator has taken. Thus, even if the reported catches are well outside of the ratio 20 : 100, it cannot be concluded only from the log-book data that the fisher concerned has been fishing inappropriately, because they may have sufficient uncaught Gummy Shark quota (or can lease it in) to cover off the expected maximum allowable ratio.

Given the School Shark quota is now set at 215 t, if the School Shark catches were matched exactly to the Gummy Shark catches this would limit the Gummy Shark catches to only 1075 t rather than the actual Gummy Shark catches, which are generally above 1500 t (**Figure 28**). As illustrated (**Figure 30**, **Figure 31**, and **Figure 34**), most vessels that have reported shark catches only take very small amounts of School Shark. Industry representative bodies such as SETFIA and the Sustainable Shark Fishing industry (SSFI) have actively encouraged their members to avoid incidental-catch-only depleted species. In addition, after it was demonstrated in 2010/2011 that the system was open to inappropriate use (Haddon, 2012), many quota owners also agreed to be more wary of leasing out relatively large amounts of quota. The outcome has been a decline in the catches of School Shark (and Blue Warehou) although given that the selectivity of the bottom-line method makes it somewhat more likely to catch School Shark the recent rise in the proportion of School Sharks to Gummy Sharks across the bottom-line fleet (see **Figure 27**) may need to be monitored more closely.

7.3 Risk Assessments for Rebuilding Species

7.3.1 Introduction

Reports from industry and industry representatives indicate that no one is currently attempting to fish for Blue Warehou (Simon Boag, pers. comm.). When the trawl fishery was active, the common practice was to “run down” Blue Warehou in relatively long tows but, especially given the increase in fuel prices, fishers now appear to have largely abandoned such practices. There are also no reports of unusual discarding of catches occurring so there is not even anecdotal evidence that Blue Warehou has increased in abundance and become less depleted; it remains a problematical species that does not appear to be recovering despite catches being at record low levels.

The harvest strategy policy makes the assumption that if catches are reduced sufficiently then recovery should occur. Catches in the Blue Warehou fishery were greatly reduced in 2009 (~60% reduction in the western fishery). If, therefore, the assumption is made that the stock remains depleted, a question is raised concerning what factor or combination of factors is preventing stock recovery? The possibilities of reduced recruitment levels and/or of higher catches than those reported actually being taken can be explored by projecting forward the assessment model fitted to data up until targeted fishing stopped in 2008.

Such an approach cannot identify which factor is responsible for a stock failing to recover but it can identify the circumstances required for a single factor to be responsible and then judgements can be drawn concerning the plausibility of such circumstances, possibly leading to some factors being considered less likely as a potential cause.

Model projections should always be treated with caution as, rather than evidence for a particular outcome, they represent the implications of the original model fit (estimates of the stock’s productivity, etc) and whatever assumptions were made then, combined with any extra assumptions made for the projections. Despite being able to give probabilistic statements about the relative likelihood of different outcomes, in themselves they do not constitute evidence to support the assumptions made when making those projections. The model itself makes the implications of the available data plus any assumptions within the model explicit, using a model does not add to the evidence.

7.3.2 Reduced Deterministic Recruitment

Projections of more than one or two years for any stock could become misleading if it is assumed that recruitment will return to the unfished level. If such recruitment levels are continued for any number of years when the stock only experiences reduced catches then significant recovery will undoubtedly be predicted. When the western Blue Warehou model was projected while applying deterministic unfished recruitment levels and removing the relatively small reported catches for 2009 - 2014, it was predicted that by 2014 the western stock should have increased to about 80% of unfished biomass. There is no evidence for such a marked level of recovery but the predicted recovery merely reflects the implausibly high level of recruitment assumed despite the previous 18 years of recruitment estimates being well below the unfished level on average. Such simplistic projections should be avoided in any future attempts to predict the potential recovery of a stock into the future. The deterministic predictions were further exaggerated through the software failing to correct for log-normal bias when estimating mean recruitment for the unfished stock. Even when the log-normal bias for the assumed recruitment is corrected, the stock should still have recovered to about the target reference point (~48%B_0).

More plausibly, when the modelled western stock was projected forward from 2006 to 2014 using recruitment levels that approximated the average recruitment from 1987 – 2005 (approximately half the recruitment levels of the unfished state) this still predicted that the stock should have exhibited strong recovery of up to about 40%B_0. It was only when recruitment levels were selected that were about 25% of the unfished level that the state of the stock in 2014 was approximately the same as that in 2008, i.e. effectively no recovery (**Table 13**; **Figure 20** and **Figure 21**). It would be a task for the resource assessment group to decide which recruitment scenario was most plausible.

7.3.3 Reduced Stochastic Recruitment

Recruitment processes are not deterministic, so, while deterministic projections can give an indication of expectations, instead of setting a constant average recruitment level it is more informative to define a distribution of levels from which to randomly sample each year of a projection and then repeat the projection numerous times (**Figure 22**).

The outcomes of the scenarios considered were similar to those from the deterministic projections except they give some notion of the uncertainty associated with each estimate. Thus, in addition to stating that the expected recovery using the recent average recruitment levels would be to 41.5%B_0 it is also possible to state that there is only a 2.5% chance that the stock recovery would be less than 28.6%B_0. This is not evidence that this truly is the case, it is simply the implication of the productivity of the stock (estimated by fitting the assessment model using data up until 2008) and then the assumptions of the projections, especially the mean level of recruitment. Nevertheless, it appears more plausible to assume recruitment levels are more likely to be similar to what they have been recently than assume implausibly high unfished average levels.

The mean recruitment deviate from 1987 – 2005 was about -0.2205, which implied recruitment levels were about 49% of unfished levels. The mean deviates had to be reduced to between -0.8 and -0.9, equivalent to between 24 – 27% of unfished levels for there to be no effective change in stock status between 2008 and 2014.

Interpreting this model outcome is somewhat more complicated because from 2008 – 2014 the TAC was initially halved and then in 2012 it was dropped by a further third (**Table 4**) and the decline in catches was even greater. Thus, the character of the fishery was rather different between 2009 – 2011 and 2012 – 2014 with catches in the latter years being only about a third of those in the first three years. As the projections using the mean recruitment levels from the years 1987 – 2005 indicate (**Table 13** and **Table 14**; **Figure 23**) the original cut in catches would have been perfectly adequate to encourage stock recovery had recruitment continued at the mean levels predicted to have occurred between 1987 - 2005. The last two negative recruitment residuals are relatively large implying very low recruitment levels, although those estimates are imprecise (**Figure 18**). If recruitment levels had declined in 2004 and 2005 and that continued on until at least 2014, then the catches across 2009 – 2011, despite being 60% smaller than the previous years would still have been too high to allow significant stock recovery. With the further catch reduction in 2012, so that catches became < 62t (and are even lower in the more complex eastern fishery), then even with the reduced recruitment the model predicts that stock recovery should have begun to occur from 2012 onwards, although that recovery would only continue slowly. It is the case, however, that there was little information in 2008 that would have suggested that such a large change in catches would have been required. It would have been possible to explore the implications of different potential recruitment levels at that time but the weight of evidence was then that recruitment would continue at something like the mean values predicted to have occurred in the previous 18 years.

There are many other potential recruitment level scenarios that could be explored, including a change in when it was suggested that recruitment levels declined. Or including a degree of auto-correlation of the recruitment deviates between years. But the relatively simple scenarios considered here certainly indicate that a decline in recruitment levels in recent years appears to be consistent with the lack of recovery in the western Blue Warehou stock.

7.3.4 Under-Reported Catches

The projections were much more sensitive to the assumed mean level of recruitment than they were to actual catches being greater than reported catches, even when they were forced to be twice as great as the reported catches. The second reduction of mean catches in 2012 greatly reduced the harvest rate (the proportion of the available stock that is taken by the fishery in a year) and it took implausibly large increases in the real catch (mortality of fish) to increase the harvest rate to a degree sufficient to prevent stock recovery (**Figure 25**; **Table 18**). It was also the case that these hypothesized implausibly large increases in real catches still had to be combined with a decrease in recruitment to have the effect of preventing stock recovery. If there had been no change in average recruitment levels then even an implausible doubling of catch would still have allowed stock recovery back up to above 35%B_0. While an under-estimation of true discard rates may have contributed a little to the failure to recover, under-reporting of catches can be rejected as being implausible on the basis of these projections.

7.3.5 The Utility of Stochastic Model Projections

The current harvest strategy policy is designed around the use of the current estimate of spawning stock biomass (or its proxy). The validity of the harvest control rules for the current Tier 1 – 4 harvest strategies in the SESSF relies on those harvest strategies having been tested using management strategy evaluation (Smith *et al.*, 1999; Wayte, 2009; Klaer *et al.*, 2009, Little *et al.*, 2011), which was able to demonstrate that if the harvest strategies are consistently applied then they should invariably lead to the limit reference points being avoided in at least 90% of outcomes and the target reference point being approached eventually.

This general strategy of using the current stock status to set subsequent catches is not the only approach possible. The most common alternative approach is to use stock assessment model projections under specified conditions of alternative fixed catches and recruitment to estimate the relative risk of different outcomes occurring in the future (Francis, 1992; Francis and Shotten, 1997). This is the strategy used in CCAMLR, and in Australia it forms the basis of management recommendations for the Patagonian Toothfish in the Macquarie Island and the Heard and Macdonald Islands fisheries. The approach of using stochastic projections is thus neither original or exceptional. The important point is, however, that this approach can be used to test assumptions and implications concerning changes in productivity, about alternative catch levels of stock status, and even for making catch recommendations for species, including depleted species, within mixed fisheries. Of course there are many assumptions made when using stochastic projections. The common objections to using such an approach is that the variation used when making the projections is invariably poorly estimated and is generally under-estimated. But there are numerous other potential objections to be made concerning the use of current estimates of spawning biomass within a catch harvest control rule. The primary difference is that the use of stochastic projections has not been tested in the SESSF using management strategy evaluation, whereas the harvest control rules have been tested. It would be necessary to make such tests to determine the effect of under-estimating the projected catches or over-estimating the recruitment productivity or perhaps changes in growth dynamics.

The current harvest strategy policy does not preclude the use of projections but, at the same time, it does not require them. Importantly, the use of stochastic projections constitutes a useful tool for exploring management options. It is not being recommended that they be used routinely but, as with all tools, it is being recommended that they should be used for the specific purposes for which they are well adapted. Limiting one's analytical options on principle has the appearance of being self-defeating. Given the uncertainties that appear to be unavoidable when using fisheries data (CPUE, size- or age-composition, effort, etc) then limiting which analytical tools can be used is too great a constraint.

7.4 Rebuilding Strategies

The harvest strategy policy requires rebuilding strategies (e.g. AFMA, 2008, 2012, 2014, 2015, 2015c) for persistently depleted species, where the term ‘depleted’ implies a species’ stock assessment estimates it to be below the species’ limit reference point.

The assumption with most fishery population models is that at low abundance there will be density dependent effects that increase the survivorship of any recruits that are produced. Other density dependent effects are possible but the main one of interest relates to improved recruitment success (not necessarily more recruits, just more surviving; Myers and Barrowman, 1996). This density-dependent effect has been shown to be strong in some species but also weak in others. Where it is weak the species concerned are far more vulnerable to failing to recover if they become depleted (Keith and Hutchings, 2012). Eastern Gemfish, for example, have been badly depleted since the early 1990s and still exhibit no signs of recovery despite greatly reduced catches.

Much of the harvest strategy policy is based on the notions of the unfished spawning biomass (B_0) and the fishing mortality that will lead to the optimum maximum economic yield (F_{MEY} or $F_{48\%}$). These ideas are based on equilibrium and deterministic theory, which may simply be inappropriate for some species. Certainly there are numerous species which are naturally enormously variable in their stock size (e.g. squid species, small pelagic fish species, commercial scallops) and such species have biological characteristics which reflect an opportunistic life style. This means that if environmental conditions become suitable their populations may boom to extremely high levels but equally, if conditions become unfavourable their populations can completely naturally crash to very low levels (with or without fishing). The HSP recognizes that some species are inherently variable but does not provide useful guidance about how to ensure their management adheres to the intent of the ‘harvest strategy policy’.

What is not recognized in the policy is that even species which are not inherently variable may undergo long term fluctuations in stock size (Cushing, 1988; Ricker, 1997; Soutar and Isaacs, 1969). Such studies of the longer-term changes in fish stocks indicate that some species can come and go even when there is no commercial fishing.

7.4.1 The Failure to Recover

The harvest strategy policy effectively requires (demands) that species will recover within the time-frame defined in the rebuilding strategy. But some species have predicted recovery times far into the future. For example, the recovery time to B_{25} for Harrison’s Dogfish is 86 years and that for Southern Dogfish is 62 year. (AFMA, 2012). These estimates are based on approximate estimates of mean age of maturity and thus mean generation times and so they remain highly uncertain. Such estimates take no account of environmental changes occurring over that time period, especially the effects that could occur as a result of increases in sea temperature (warmer) and decreases in pH (more acid). These statements are not meant to imply these species will not recover it is merely to illustrate that the deterministic theory that states recovery will occur means that it would be prudent to develop guidance and recommendation for how to respond should any species fail to recover despite management intervention. In addition, there should be some recognition that, by chance alone, recovery may take longer (or shorter) than expected.

The lack of guidance on how to respond if a species fails to recover in the expected time-frame is an important gap in the current policy and its guidelines. At least recognition that the natural world does not always follow the predictions of relatively simple models would help managers to understand the full range of possible stock responses that can occur when management is imposed.

7.4.2 Blue Warehou's Failure to Recover

Blue Warehou is one of the depleted species which does not appear to be exhibiting any signs of recovery (large fish remain difficult to find, discards are not rising, industry are not complaining that they are having trouble avoiding this species).

One of the problems with rebuilding species is that the avoidance that follows the introduction of an incidental-catch TAC leads to a lack of credible data on stock status so the stock status performance measures available become less quantifiable; e.g. the number and scope of industry complaints. The work presented here on stochastic projections suggests that if the assumption of no significant stock recovery to the end of 2014 is in fact the case in the western stock of Blue Warehou, then it is more likely that a decline in the recruitment dynamics has occurred than the alternative of catches being greater than the combined reported catches and discards.

Numerous alternative hypotheses have been proposed as candidate explanations for why recruitment may have declined in Blue Warehou. It is known, for example, that the south-east Australian oceanographic environment is undergoing trends in temperature and changes in the wind patterns, which have been implicated in changes in the marine system in the same region (Ridgway, 2007a, b; Hill *et al*., 2008; Johnson *et al*., 2011; Last *et al*., 2011). A link between these environmental changes and changes in Jackass Morwong dynamics has already been suggested (Wayte, 2013).

The processes that relate spawning stock size to subsequent recruitment are neither deterministic nor are they necessarily stable through time. Environmentally driven changes in productivity are commonly recognized in northern hemisphere fisheries (Jacobson and MacCall, 1995; Vert-pre *et al*., 2013; Essington *et al*., 2015; King *et al*., 2015; Szuwalski and Hilborn, 2015). One conclusion by Vert-pre *et al*. (2013) summarizes the situation there:

> *"Fisheries management agencies need to recognize that irregular changes in productivity are common and that harvest regulation and management targets may need to be adjusted whenever productivity changes."* (Vert-pre et al., 2013, p1779)

This is not claiming that imposed fishing mortality rates have not been a problem for on-going stock depletion. It seems likely, given the very large increases in the catches of Blue Warehou in the late 1980s and early 1990s, which can now be seen to be well above the level of productivity in the Blue Warehou stocks, that the stocks were driven down to levels where they would be less resilient to other factors influencing their population dynamics. Given a large reduction in the recruitment productivity, potentially because of environmental forcing, and with the stock already low in the mid-1990s, when catches were eventually reduced the stock was no longer in a position or capable of recovery.

However, rather than reduced recruitment an alternative explanation might be that natural mortality (perhaps lack of suitable food or increased predation) has increased on some early life-history stage of Blue Warehou. But as recruitment in the model relates to the post-larval 0+ year old fish, some increased mortality scenarios would be contributing to reduced recruitment directly and could not be distinguished from it.

The assumption that a stock will definitely recover if catches are reduced or stopped ignores the fact that recruitment processes are inherently difficult or impossible to predict. There has already been one example of a change in the productivity in one of the previously important SESSF species, Jackass Morwong (Wayte, 2013), where it was argued that changing oceanographic conditions affected recruitment patterns. Attempting to positively connect changes in the dynamics of fish stocks with changes in oceanographic dynamics is very difficult and invariably can only go as far as correlative studies, perhaps including time lag effects.

A major concern would be if such failures of stocks to recover is a signal that the productivity of Australia's eastern coastline is declining. Northern, relatively warm waters are generally not as nutrient rich as the colder more southerly waters (Haddon, 2007c) and given their increased incursion into waters off New South Wales, Victoria, and Tasmania, a decline in productivity is not unexpected.

Currently, when setting non-target TACs for species in need of rebuilding it is possible to use the companion species methodology to determine the expected catch of a species when it is not being targeted. It is recommended that, at least if the depleted species concerned is a Tier 1 species, then exploratory stochastic projections should also be made assuming different levels of catch (perhaps informed by the companion species analysis) along with different assumptions concerning the future recruitment. In this way, the likelihood of recovery could be determined, and in addition, what would be required for recovery to fail. By making more explicit predictions about what might be expected in the future the number of potential performance measures that might be used could increase.

For example, with Blue Warehou, there have been verbal reports in recent RAG meetings that there are large numbers of small juveniles Blue Warehou of non-commercial sizes to be found in parts of the coast. However, it is clear that very few of these juveniles are surviving into the larger mature size classes. This suggests that increased mortality or failure to grow and mature may be behind the lack of recovery of the spawning biomass rather than simply be a reduction in successful reproduction. Providing more options concerning stock status or stock limitations that can be tested or examined using evidence from the fishery increases the potential for understanding what is happening to these depleted stocks, and hence may assist in their management.

7.4.3 Rebuilding and Economics

The vagaries in the harvest strategy policy's text with respect to the rebuilding target and how it is achieved stem from the use of 'may be appropriate' in the statement:

"*For a stock below B_{LIM} a rebuilding strategy will be developed to rebuild the stock to B_{TARG}. Once such a stock is above B_{LIM} it may be appropriate for targeted fishing to re-commence in-line with the stock rebuilding strategy and HS.*" (DAFF, 2007, p 24)

While that needs clarification there is also an issue with respect to the speed with which a stock is expected to recover. The Guidelines also state"

'…*the optimal time path to rebuild a stock has an economic component. In determining the optimal time path to rebuild a stock, there is a trade-off between lost profits in the short term and the speed at which the stock is rebuilt*' (DAFF, 2007, p. 43).

Despite this statement the trade-off between time to recovery and impact of management restrictions does not appear to be have been considered explicitly in any of the currently seriously depleted species. The economic component reflects the idea that there is likely to be a range of incidental-catch TAC levels from 0 to some maximum that would still permit stock recovery albeit at a slower rate and over a longer time frame. The economic implications constitute a trade-off between the time taken to recover a stock and the potential economic losses brought about by restricting the catch of one species, which may have technical interactions with other species and hence restrict their catches also. This appears to be happening with Gummy Shark and School Shark, although this scenario is somewhat obscured by additional management decisions lowering the Gummy Shark quota so as to increase average catch rates and thereby improve profitability.

The effects of such technical interactions are difficult to separate from other factors that can effect catch rates, catches and the distribution of effort. Nevertheless, it would appear that the arrangements between Gummy Shark and School Shark would be excellent candidates for an economic review to determine whether the incidental-catch TAC for School Sharks is interacting with other management interventions in a positive or negative manner for the fishery.

7.5 Guidelines for Data-Rich Species

Relatively data-rich species are those with an index of relative abundance that generally is believed to track the abundance of the stock and has representative size-and age-composition data from the catches, and possibly other data informative about the stock's dynamics (such as tagging data informing about movement patterns). The guidelines for how to set incidental-catch TACs and then how to monitor the species progress are reasonably clear with some novel aspects (see section 6.1, p30 and especially **Figure 2**). The three suggested steps to follow after setting an incidental-catch TAC (using stochastic projections to test different plausible scenarios and possibly even set incidental-catch TACs, routinely test for successful avoidance, and stop routine ISMP sampling if the data can be shown to be un-representative) all need to be agreed upon and to be approved by the SESSF RAG and individual RAGs. The RAGs have already seen value in and applied the use of stochastic projections to test alternative hypotheses for a failure of stocks to recover (Haddon, 2015c).

7.6 Applications to Data-Poor Species

Data-poor species may only have catches and catch-rates, and really data-poor species within the Commonwealth (and especially in the States) may even only have catch data, which may itself be only sporadic reflecting opportunistic fisheries (e.g. aquarium fisheries; the western deepwater trawl fishery). The real difficulty with such fisheries is determining whether or not they are stressed. If a fishery at least has operational limit reference points defined, then presumably there will be assessment methods that will allow a determination of where the fishery is with respect to its reference point(s). It is likely that stock assessments on data-poor species may be highly uncertain, but the assumed default in the HSP, to determine whether a limit has been breached, is if the median estimate of whatever performance measure(s) in use is below the limit reference point.

It is possible that some of the model-assisted data-poor stock assessment methods now available (e.g. Catch-MSY and Depletion-Based Stock Reduction Analysis; Martell and Froese, 2013; Dick and MacCall, 2011) can generate estimate of the same biological reference points as those estimated in relatively data-rich species, although with much higher levels of uncertainty. Certainly these methods provide estimates of both limit- and target- reference points. However, the data-poor harvest strategies that have been tested to date in Australia (Haddon *et al*., 2015) have yet to be formally accepted and have not yet been extended to provide for the notion of an estimate of an incidental-catch TAC. The Catch-MSY method (Martell and Froese, 2013) was only recommended for further study and was not tested in Australia. Yet this is the approach that appears to hold the greatest promise for the assessment and management of data-poor species.

Of course, if there can be no explicit limit reference point produced (for example, the Western Deep Water Trawl Fishery currently only has catch triggers rather than reference points) then management is limited to a weight of evidence approach and the use of ecological risk assessment (Hobday *et al*., 2011). Under such circumstances it would not be possible to know whether a stock was extremely depleted or not.

7.6.1 Threatened, Endangered, and Protected Species

Given the relatively poor observer coverage (exceptions occur, e.g. the Australian sub-Antarctic fisheries have had 200% observer coverage since 1994) leading to the possible under-reporting of the by-catch of threatened, endangered, and protected species (TEPs) developing useful performance measures for assessing the status of TEP species would not be straight-forward. Nevertheless, simulation studies, where the dynamics of the species considered at risk are modelled, can be successfully conducted. These are the equivalent of the stochastic projections recommended for depleted commercial fish species. In this way alternative scenarios can be considered and compared to explore the utility of alternative management and mitigation options. For example, Tuck (2011) used a simulation model to test the often used bycatch rate trigger for seabirds , and concluded:

"…that using by-catch rates [of seabirds] *as a measure to assess performance of the fishery and to reduce by-catch is, under many circumstances, not sufficient to achieve conservation goals. By-catch rates can be within the limit recommended by management, giving the impression that the fishery has reduced by-catch to sustainable levels, when in fact the low rates are due to the populations having collapsed. The interpretation of by-catch rates, and any subsequent by-catch rate management rules, needs to be considered with respect to changes in fishing effort, to population-specific impacts, to levels of compliance and to the robustness of the by-catch rate estimate. Simply apply-*

ing a by-catch rate control rule without caution can lead to catastrophic results for incidentally caught species." Tuck *et al*. (2011)

In addition, Tuck (2011) showed that a bycatch rate trigger rule that blindly combines the bycatch rates across multiple species, rather than having species-specific triggers, can mask the collapse of less common species.

Currently, in Australia, the notion of an acceptable bycatch level of TEP species is not part of the management of commercial or recreational fisheries so the applicability of the methods discussed here for setting incidental-catch TACs are not applicable. Instead, bycatch rates are the main performance measure that is monitored. Nevertheless, the principles behind examining the potential outcomes of increased mortality and the ideas of Potential Biological Removals are well developed in the literature available in relation to TEP species. The utility of using simulation assessment to examine the implications of management and of the levels of bycatch that may occur, even for TEP species, can be used to illustrate the importance of alternative mitigation measures and the consequent likely population trajectories.

7.7 Further Development

The three suggestions in the guidelines for rebuilding species that have not been formalized to date are to automatically test for a lack of avoidance where possible, to stop ISMP sampling once such sampling is considered to have become un-representative, and to conduct stochastic projections to test for the plausibility of recovery under different scenarios of catch and recruitment dynamics.

There are many different ways of doing or deciding each of these recommendations and so the next steps should be to formalize these steps, possibly using the methods currently developed, but to do so explicitly with the approval of the RAGs, especially SESSF RAG. Analyses of avoidance of rebuilding species may now have to be conducted by AFMA (because of the need to be aware of quota holdings by individuals) but even so formal reporting of findings should be presented to the RAGs.

Decisions are needed as to how to decide when ISMP data could no longer be considered representative or has become so variable between years as to have become uninformative. Development of a standard set of diagnostic analyses and plots would greatl assist with this. This was not attempted in this project as it would involve a number of retrospective analyses and, ideally, a detailed management strategy evaluation that attempted to determine the level of inter-annual variation or spatial heterogeneity required for that data to become uninformative. This issue is important not only to rebuilding species but to all assessed species which use ISMP data. Currently the assumption is made that the data collected is representative of the whole stock sampled and for many species this is questionable (as was recognized in 2015 for Blue-eye Trevalla (*Hyperoglyphe antarctica*).

Stochastic projections using Stock Synthesis 3 can be and have been implemented in more than one way. Standard methods still need to be settled upon, which can be transferred to those species not using SS3 (e.g. School Shark) and finally they need to be agreed to by SESSF RAG.

8 Extension and Adoption

The analyses and ideas stemming from this work were being developed before this project was able to start. This has meant that as the development of methods or new ideas has occurred they have already been presented to the Resource Assessment Groups and Management Advisory Committees within the SESSF.

Thus, the full articulation of the Companion Species approach has gained acceptance for setting the incidental-catch TAC for two of the depleted species that currently appear to be failing to recover (eastern Gemfish and Blue Warehou).

Simple data analytical and plotting algorithms were developed to examine fisheries logbook data down to the level of individual shots so as to examine the potential for systematically failing to avoid incidental-catch-only species. These have already been used to search for surreptitious targeting, or at least a negligent failure to avoid catching School Sharks and Blue Warehou. In the case of School Sharks these analyses were instrumental in the introduction of the need for fisheries to hold at least five times as much Gummy Shark quota (either caught or uncaught) than the amount of School Shark that has been taken (see Appendix 12, p100). It also demonstrated that, especially on the east coast, there was no indication that there had been any systematic failures to avoid Blue Warehou.

The ideas included here relating to rebuilding species and their implications, were to some extent included in a technical review of the current Harvest Strategy Policy, that should be contributing to the present review of the HSP (Haddon *et al.* 2013).

The use of stochastic projections for examining the plausibility of different hypotheses for a lack of rebuilding were presenting in 2015 to the SESSFRAG with respect to Blue Warehou (Haddon, 2015c). Deterministic projections for just a few years have been used since 2012 to make the projections necessary for testing breakout rules applied to multi-year TACs in the SESSF (Haddon, 2015d; Klaer *et al*., 2015).

Even though much of this material has already been presented and considered by AFMA, the RAGs, and the MACs in the SESSF, it has not been presented as a whole with respect to incidental-catch TAC setting for depleted species and its implications. The guidelines, listed in the non-technical summary and in section 6.1 (p30), are new and indicate some novel directions to pursue that will be presented to the next SESSF RAG to be held in March/April 2016.

9 Appendix 1: Intellectual Property

There are no issues concerning intellectual property relating to this research project.

10 Appendix 2: Staff

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12 Appendix: 2015 Annual Operating Condition

The 2015 annual operating conditions within the SESSF (AFMA, 2015b) contained the following detailed with respect to the capture of School sharks. The intent was to control the capture and potential for targeting of the rebuilding School shark:

Shark Obligations

9. Retained and/or landed School Shark (*Galeorhinus galeus*) and Gummy Shark (*Mustelus antarcticus*) must exceed 450 millimeters when measured in a straight line from the middle of the posterior edge of the aftermost gill-slit to the ventral insertion of the caudal fin.

10. The holder must not take, or engage in fishing for, the species School Shark (*Galeorhinus galeus*) unless:
    a) the holder holds five times more Gummy Shark (*Mustelus antarcticus*) quota (caught and uncaught) than the amount of School Shark that the holder has taken; or
    b) at the end of the:
        i. first period, the holder has taken less than 250 kilograms of School Shark (trunked weight) in that period;
        ii. second period, the holder has taken less than 500 kilograms of School Shark (trunked weight) in that period; or
        iii. third period, the holder has taken less than 750 kilograms of School Shark (trunked weight) in that period.

11. In these conditions:
    a) ‘first period’ means the roughly three month period from 1 May through to the last Friday in July of each fishing year;
    b) ‘second period’ means the roughly six month period from 1 May through to the last Friday in October of each fishing year; and
    c) ‘third period’ means the roughly nine month period from 1 May through to the last Friday in January of each fishing year.

12. For the purpose of determining compliance with these conditions, the holding of caught and uncaught quota of Gummy Shark and amount of School Shark taken must be calculated on each quota and catch balancing date, being:
    a) 5pm Eastern Standard Time 12 August of each fishing year, for the first period. If 12 August falls on a weekend or a public holiday, the balancing date moves to the next business day;
    b) 5pm Eastern Standard Time on 11 November of each fishing year, for the second period. If 11 November falls on a weekend or a public holiday, the balancing date moves to the next business day; and
    c) 5pm Eastern Standard Time on 14 February of each fishing year for the third period. If 14 February falls on a weekend or a public holiday, the

balancing date moves to the next business day.

Note: For example, if, at the end of the first period the person has taken 600 kilograms of School Shark, the holder must hold at least 3 tonnes of Gummy Shark quota (600 kilograms x 5) on the 'quota and catch balancing date'.

13. If any school shark (*Galeorhinus galeus*) are taken alive, they must be returned to the water alive.

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