# Benchmarking Australia's small pelagic fisheries against world's best practice

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# Acknowledgments

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# Executive Summary

**Overview**

This report documents the outcomes of an international technical workshop and a stakeholder forum on fisheries for small pelagic species that were held at the South Australian Research and Development Institute (SARDI) over 14-18 July 2014. The objective of the technical workshop was to benchmark Australia's fisheries for small pelagic species against world's best practice. The objective of the stakeholder forum was to provide stakeholders with an opportunity to compare approaches taken in Australia's small pelagic fisheries to those taken elsewhere.

Discussions at the technical workshop suggested that the assessment and management frameworks for Australia's fisheries for small pelagic species, especially the South Australian Sardine Fishery (SASF), are consistent with world's best practice with respect to:

- application of fishery-independent stock assessment techniques such as the Daily Egg Production Method (DEPM);
- establishment and use of formal harvest control rules or operational management procedures (i.e. harvest strategies);
- assessment of the ecosystem effects of fishing;
- mitigation of operational interactions with wildlife.

Participants in the technical workshop also considered that it was appropriate that the Commonwealth Small Pelagic Fishery (SPF) is building on the approaches that have supported the successful development of the SASF. It was generally agreed that concerns regarding the risks of localised depletion in the SPF may be best addressed by establishing precautionary harvest guidelines based on existing knowledge.

Participants in the stakeholder forum considered that the assessment and management framework for the SASF compared well to other fisheries worldwide. Most concerns related to the introduction of a large freezer-trawler into the SPF. Industry expressed concerns about political intervention into fisheries management related to introduction of this vessel and "unrealistic" expectations regarding the level of scientific information required prior to the commencement of the fishery. Other stakeholders expressed concerns that non-industry views were not given adequate consideration by fisheries management agencies or scientists and that more research was needed before the SPF is developed. It was widely agreed that effective communication among stakeholders and a genuine co-management approach should be re-established in the SPF.

**Background**

Assessment and management of Australia's fisheries for small pelagic fishes are of particular concern to several stakeholder groups, including conservationists and recreational fishers. The introduction of a large freezer-trawler into the SPF generated considerable media attention and led to the implementation of a two year moratorium on fishing vessels >140 m operating in Australian waters. Issues that generated particular interest were: the reliability of estimates of spawning biomass obtained using the DEPM; operational interactions with threatened, endangered and protected species; potential trophic effects on other components of the ecosystem; and possible impacts of localised depletion on predatory species and other fisheries.

The technical workshop and stakeholder forum were conducted in response to advice obtained from a wide range of stakeholders that the research and management systems of Australia's fisheries for small pelagic fishes should be benchmarked against world's best practice to identify opportunities for improvement.

**Objectives**

1. Benchmark the research and management frameworks for Australia's fisheries for small pelagic fishes against world's best practice and identify opportunities for improvement.
2. Provide the Australian community with the opportunity and information required to objectively assess how Australia's fisheries for small pelagic species compare to other fisheries worldwide

**Methods**

A four day technical workshop and one day stakeholder forum on small pelagic fisheries were held at SARDI, West Beach, South Australia during 14-18 July 2014. Six international and nine Australian scientists gave presentations. Facilitated discussions of key issues were conducted each day. The first three days focused on the DEPM and harvest strategies for small pelagic fisheries. The fourth day focused on ecological issues, including operational interactions with marine mammals, trophic implications and localised depletion.

The fifth day was the stakeholder forum which included an overview of issues discussed at the technical workshop and presentations from key stakeholders. Fisheries managers, industry representatives, environmental groups and recreational fishers attended. The forum provided stakeholders with an opportunity to engage directly with fisheries scientists and managers and evaluate for themselves how well Australia’s pelagic fisheries compared to others around the world.

**Results, Discussion and Conclusions**

*Technical workshop*

Presentations and discussions at the workshop demonstrated that the assessment and management frameworks for the SASF compare favourably to other small pelagic fisheries worldwide. It was noted that a suite of research projects is currently underway to further improve these approaches and support the adaptive management of the SASF and SPF. It was recognised that basing the development of the SPF on approaches used in the successful development of the SASF was appropriate. Scientific participants emphasised that it was not possible to know everything about a stock before fishing commences and that fisheries need to be managed adaptively.

The scientific panel of international experts considered that the application of the DEPM in Australia compared favourably to other fisheries and noted that ongoing refinements of the DEPM are underway in several countries. Several options for improving statistical methods used to estimate egg production in Australia and elsewhere were identified. The importance of FRDC Project 2014/026 that is developing guidelines for estimating egg production was widely acknowledged. It was recognised that South Australia is the only jurisdiction in which adult samples are collected using gillnets and the benefits of conducting a research project to compare estimates of adult parameters obtained using gill-nets, purse-seine nets and trawl nets was identified. It was also suggested that the approaches used to estimate spawning fraction in the SASF should be reviewed, noting that a similar review has been conducted in the Bay of Biscay Anchovy Fishery.

The harvest strategy for the SASF was considered to be similar to those used in comparable fisheries and consistent with international benchmarks for low trophic level species (e.g. Marine Stewardship Council;

Lenfest Task Force). However, the SASF was the only fishery considered at the workshop where estimates of spawning biomass are used directly to set Total Allowable Catches (TACs). It was recognised that a project to examine the benefits and limitations of using a population model and/or DEPM estimates of spawning biomass to set TACs was warranted. Structuring the SPF harvest strategy around conservative exploitation rates was considered to be appropriate for a developing fishery.

The establishment of size-based performance indicators to address reductions in the abundance of adult Sardines (*Sardinops sagax*) on key fishing grounds was recognised as being a precautionary and innovative approach to managing potential ecosystem impacts. It was generally agreed that consideration should be given to establishing precautionary harvest guidelines to reduce the risk of localised depletion in the SPF.

International scientists considered that the SASF compared well to most other fisheries in the assessment and management of ecosystem effects, including consideration of trophic impacts and monitoring and mitigation of interactions with protected species. Few other fisheries have conducted comprehensive field-based assessments of the role of the target species in the ecosystem and developed system-specific ecosystem models to assess potential ecosystem impacts. The benefits of establishing an ongoing ecosystem program comparable to the investigation of the role of the Pacific Sardine (*Sardinops sagax*) in the California Current System that began in 1949 were widely acknowledged. It was recommended that ecosystem studies similar to those done in the SASF should be conducted for the SPF if/when it is developed into a substantial fishery.

*Stakeholder forum*

The stakeholder forum was well attended by industry stakeholders but relatively few conservation and recreational fishing stakeholders were present. Participants acknowledged that the assessment and management framework for SASF compared well to fisheries for small pelagic fishes around the world. Most concerns expressed by stakeholders related to issues associated with the introduction of a large freezer-trawler into the SPF. Industry stakeholders expressed concerns that political intervention into fisheries management over this issue set a dangerous precedent and that conservation and recreational fishing stakeholders had “unrealistic” expectations regarding the level of scientific information that should be acquired prior to the development of a fishery. Some conservation and recreational fishing stakeholders expressed concerns that their views were not given adequate consideration by fisheries management agencies (and scientists) and that more research was needed before large-scale harvesting should commence in the SPF. The disparate views of stakeholder groups were not resolved at the forum. However, it was widely agreed that effective communication among stakeholders and a genuine co-management approach should be re-established to support future management of the SPF.

**Recommendations and further development**

The workshop identified several areas of research that should be undertaken to improve the assessment and management frameworks of Australia’s fisheries for small pelagic fisheries, including: 1) comparing estimates of adult parameters obtained using gill-nets, purse-seine nets and trawl nets; 2) reviewing approaches taken to estimating spawning fraction; and 3) examining the benefits and limitations of using a population model and/or DEPM estimates of spawning biomass to sets TACs.

**Keywords**

Small pelagic fishes, South Australian Sardine Fishery, Commonwealth Small Pelagic Fishery, Daily Egg Production Method, egg production, spawning fraction, batch fecundity, harvest strategies

# Introduction

## Background and Consultation

During the debate in 2012 regarding the introduction of a large factory trawler into the Commonwealth Small Pelagic Fishery (SPF), the Australian community clearly articulated its expectation that the research and management systems for Australia's fisheries for small pelagic (forage fish) species should match or exceed world's best practice (Tracey et al. 2013). Current international standards for research and management of forage fish species are described by Smith et al. (2011) and Pikitich et al. (2013).

Issues identified as being of particular interest to key stakeholders, including conservationist groups and recreational fishers included: the reliability of estimates of spawning biomass obtained using the Daily Egg Production Method (DEPM, Parker 1980); operational interactions with threatened, endangered and protected species; potential trophic effects on other components of the ecosystem; and possible impacts of localised depletion on predatory species and other fisheries (Tracey et al. 2013).

These issues are all being addressed as part of the ongoing assessment and management of Australia's fisheries for small pelagic fishes. However, following recommendations by the Research and Management Committee of the South Australian Sardine Fishery (SASF), the Resource Assessment Group for the SPF and the Australian Fisheries Management Authority (AFMA), research projects have been funded to evaluate the current harvest strategies for these fisheries (FRDC Project 2013/028, "Review and update harvest strategy settings for the Commonwealth Small Pelagic Fishery), improve current stock assessment methodologies (FRDC Project 2014/026, "*Improving the precision of estimates of egg production and spawning biomass obtained using the Daily Egg Production Method*") and undertake DEPM surveys of SPF stocks (FRDC Project 2013/053, "*Summer spawning patterns and preliminary Daily Egg Production Method surveys of Jack Mackerel and Australian Sardine off the East Coast*"; FRDC Project 2014/033, *Egg distribution, reproductive parameters and spawning biomass of Blue Mackerel, Australian Sardine and Tailor off the East Coast during late winter and early spring*").

This technical workshop and stakeholder forum was conducted to respond to advice obtained from a wide range of stakeholders that the research and management systems of Australia's fisheries for small pelagic species should be benchmarked against world's best practice to identify opportunities for improvement.

References cited in the report are listed in Appendix 1.

## Need

The technical workshop and stakeholder forum were needed to address concerns expressed by stakeholder groups and the broader Australian community during the recent "super-trawler debate" that the current assessment and management framework for the SPF may have technical deficiencies and not be consistent with world's best practice.

The workshop and forum were also needed because these concerns have the potential to undermine stakeholder and community confidence in other Australian fisheries for small pelagic fishes, such as the SASF.

The technical workshop provided an efficient and transparent mechanism by which to benchmark the research and management frameworks of Australia's fisheries for small pelagic species against world's best practice and identify opportunities for improving current approaches.

The stakeholder forum provided key stakeholders and the broader community with the opportunity and information required to objectively assess how Australia's fisheries for small pelagic fishes compare to other fisheries worldwide. This forum was a critical step towards re-establishing stakeholder and public confidence in the assessment and management framework for the SPF. It was also needed to help maintain a social license to operate for other Australian fisheries for small pelagic species, such as the SASF.

Specific issues that had been identified as matters of stakeholder and public concern and that were addressed in the technical workshop and stakeholder forum included:

1. Options for increasing the reliability of estimates of spawning biomass obtained using the DEPM;
2. Opportunities to reduce operational interactions with threatened, endangered and protected species;
3. Potential for improving current approaches to assessment and mitigation of potential trophic effects on other components of the ecosystem;
4. Innovative methods for reducing possible impacts of localised depletion of prey on predatory species and other fisheries (especially recreational fisheries) that target small pelagic fishes for bait and fish for their predators.

# Objectives

The objectives of the technical workshop and stakeholder forum were to:

1. Benchmark the research and management frameworks for Australia's fisheries for small pelagic fishes against world's best practice and identify opportunities for improvement.

2. Provide the Australian community with the opportunity and information required to objectively assess how Australia's fisheries for small pelagic species compare to other fisheries worldwide.

# Methods

A four day technical workshop and one day stakeholder forum on small pelagic fisheries were held at South Australian Research and Development Institute (SARDI), West Beach, South Australia during 14-18 July 2014.

Six internationally renowned scientists from outside Australia (USA, Chile, Spain, Portugal, Netherlands, Greece) with expertise in small pelagic fishes gave presentations about their research and the fisheries in which they have been involved (Appendix 2). Nine Australia scientists working in this field also attended and made presentations on their work on small pelagic fishes and their ecosystems and fisheries both in Australia (i.e. South Australia, Tasmania, Queensland) and elsewhere (Antarctica) (Appendix 2).

Fisheries managers from the South Australian and Commonwealth Governments also made presentations, as did representatives from the fishing industry (SASF, SPF) (Appendix 2). Speakers from environmental groups (World Wildlife Fund) and with interests in marine conservation and recreational fishing also attended and presented, albeit in limited numbers (Appendix 2, 3).

The objective of the first two days of the technical workshop was to present overviews of several major fisheries for small pelagic fishes which use egg production methods for stock assessment (Appendix 4, 5, 6) 6):

- SASF (Ward);
- Californian Sardine Fishery (Lo);
- Chilean Sardine and Anchovy Fishery (Cubillos);
- Bay of Biscay Anchovy Fishery (Ibaibarriaga);
- Atlantic Sardine and Horse Mackerel Fisheries (Angelico);
- European Mackerel (van Damme).

The presentations focused on technical aspects of the application of egg production methods in these fisheries. The afternoon of the second day was conducted as a facilitated discussion which evaluated different approaches currently being used to estimate spawning area and egg production (Appendix 6).

On the morning of the third day of the workshop the focus of the workshop turned to a consideration of methods used to estimate adult reproductive parameters (Ganias) and some innovative developments in the application of the DEPM to new species (Saunders, Steer, Keane). An overview of statistical approaches used in the application of the DEPM was also presented (Carroll).

A facilitated discussion was undertaken to assess the implications of presentations and findings for the application of the DEPM in Australia's fisheries for small pelagic species.

During the afternoon of the third day the focus of the workshop was expanded to include a consideration of how biomass estimates are used to set quotas. This session began with an overview of harvest strategies (Sloan) and was followed by descriptions of the application of harvest control rules in fisheries for small pelagic species in Australia (Ward), the USA (Lo) and Europe (Ibaibarriaga, Angélico, Damme). A facilitated discussion was undertaken to identify key elements of the ideal harvest strategy for small pelagic fisheries (Appendix 5, 6).

The fourth day of the technical workshop focused on assessment and mitigation of the ecological impacts of fisheries for small pelagic species. The first talk provided an overview of international perspectives (Smith) and this was followed by presentations of case studies for Antarctic (Melbourne-Thomas) and South Australian (Goldsworthy) fisheries. Two presentations on the assessment and mitigation of operational interactions with marine mammals (Lyle, Ward) were followed by an industry perspective on its role in ensuring ecological sustainability (Watson). The afternoon session considered definitions and options for mitigating the impacts of localised depletion of small pelagic fishes (Appendix 5, 6).

The stakeholder forum began with presentations from industry (Geen, Watson), a recreational fisher (Pike), conservationist (Graham) and World Wildlife Fund (McCrea). Overviews of the fisheries in Australia (Ward), USA (Lo), Chile (Cubillos), Spain (Ibaibarriaga), Atlantic Ocean (Angélico, van Damme) and Mediterranean Sea (Ganias) were then presented (Appendix 5, 6). A facilitated panel discussion was held to assess how Australia’s pelagic fisheries compared to others around the world and identify opportunities for improvement.

# Results

## International Workshop

### Overview of the Fisheries

***Commonwealth Small Pelagic Fishery (Appendix 6.1, Buxton)***

The SPF is divided into two zones (East and West). There are four target species: Jack Mackerel (*Trachurus declivis, T. murphyi*), Blue Mackerel (*Scomber australasicus*), Redbait (*Emmelichtys nitidus*) and Australian Sardine (*Sardinops sagax*). The harvest strategy is similar to that of the SASF and is based on the DEPM. Recent catches are limited by economic constraints and are below the maximum sustainable level. The schooling behaviour of SPF species means that catch per unit effort (CPUE) provides minimal information about stock status. Due to the limited information available and potential for variations in availability and abundance, $B_0$ and $B_{MEY}$ are not suitable reference points. Fishing is currently located near processing and transport infrastructure, creating potential for localised depletion. Small pelagic species are important food sources for threatened, endangered and protected species (TEPS). The SPF harvest strategy takes into account the ecosystem roles of the target species. Because target species are caught in high volumes and have low unit value, the most efficient way to harvest may be large factory freezer vessels.

***South Australian Sardine Fishery (Appendix 6.2, Ward)***

The SASF was established in 1991 to provide fodder for the Southern Bluefin Tuna (*Thunnus maccoyii*) farming industry. The fishery developed rapidly despite significant challenges, including mass mortality events in 1995 and 1998 which each killed >60% of the adult population. It is now Australia's largest volume fishery. The majority of the catch is taken from southern Spencer Gulf. The fishery is managed using a range of input (net size, mesh size) and output controls (Total Allowable Catch, TAC and Individual Transferable Quotas, ITQs). There are 14 licence holders. Two separate management zones (Gulfs, Outside) have recently been established (Figure 1). The annual catch increased from 10 t in 1991 to ~38,000 t in 2005 and ranged between 30,000 t and 34,000 t from 2007 to 2014 (Figure 1). The TAC for 2015 is 38,000 t.

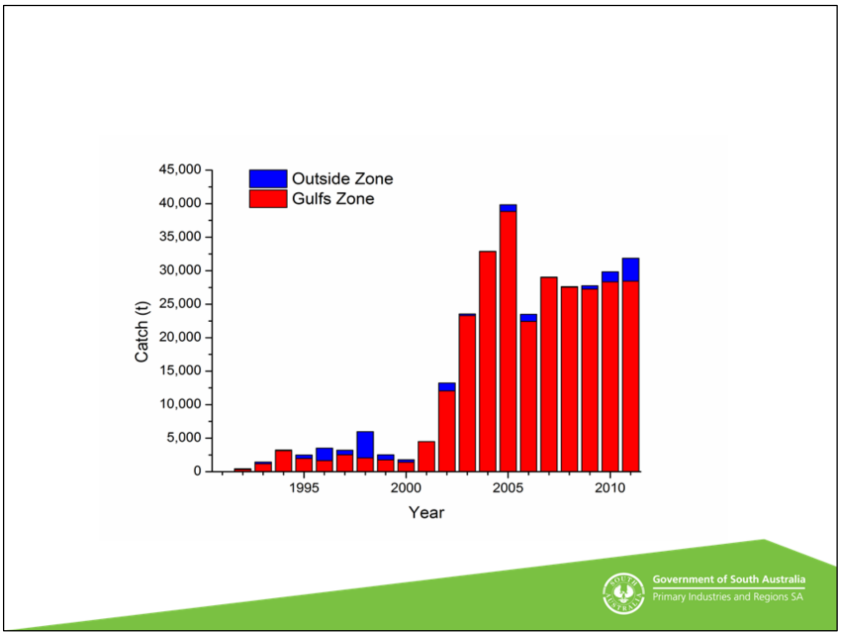



**Figure 1.** Annual catches in the South Australian Sardine Fishery from 1992 to 2011 (Appendix 6.2, Ward)

### *USA West Coast Sardine Fishery (Appendix 6.3, Lo)*

The fishery for Pacific Sardine (*Sardinops sagax*) off the west coast of the USA began around 1915. Catches off California peaked at ~700,000 t in the early 1940s; significant catches were also taken from Oregon and Washington (the Pacific North West) and British Columbia during this period (Figure 2). The population started to decline in the 1940s, and a moratorium on taking Pacific Sardine off California was enforced from 1967 to 1986. Commercial fishing re-commenced off California and Mexico in the mid-1980s and expanded into the Pacific North West and Canada during the 1990s. A TAC has been established but not ITQs. The total catch for the west coast's northern subpopulation was 112,959 t in 2008 and declined to 23,361 t in 2014. The fishery was closed in 2015.

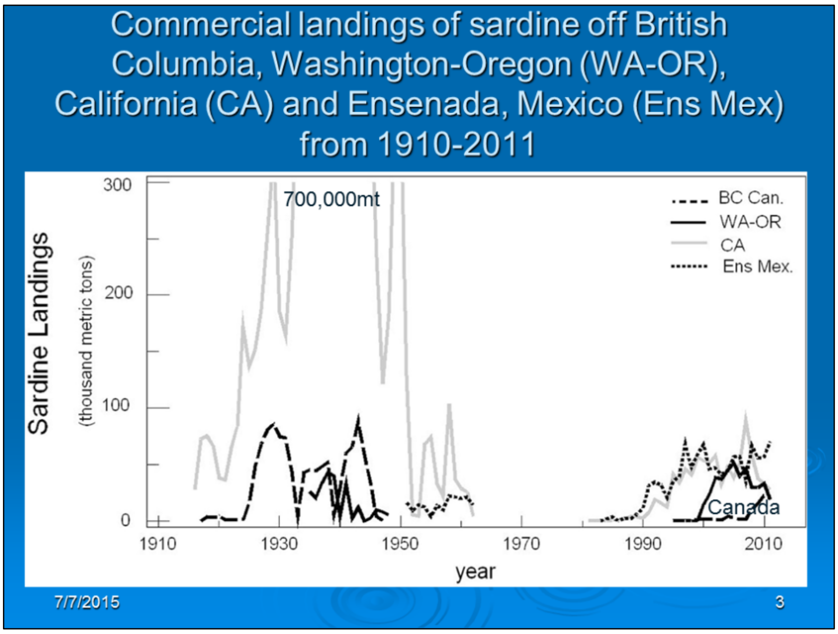



**Figure 2.** Annual catches of Pacific Sardine (*Sardinops sagax*) off the west coast of North America from 1910 to 2011 (Appendix 6.3, Lo)

### *Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)*

The Chilean Small Pelagic Fishery is located in the Humbolt Current System, which is a highly productive eastern boundary current system that supports highly fluctuating abundances of pelagic fish. Common Sardine (*Strangomera bentincki*) and Anchovy, (*Engraulis ringens*) are taken off central Chile. The total catch has ranged from ~500,000 to 1,200,000 t from 2000 to 2012 (Figure 3). An industrial fleet of 25-27 vessels operates in waters outside five nautical miles from the coast, and an artisanal fleet of ~600 vessels fishes in waters 1 to 5 nautical miles from the coast. Approximately 80% of the catch is taken by artisanal fishers and 20% in the industrial fishery. Currently, Anchovy is overexploited and Common Sardine is fully exploited. Species quotas are allocated by fishing fleets, space-time factors and vessels, with landings being monitored to ensure compliance with catch limits.

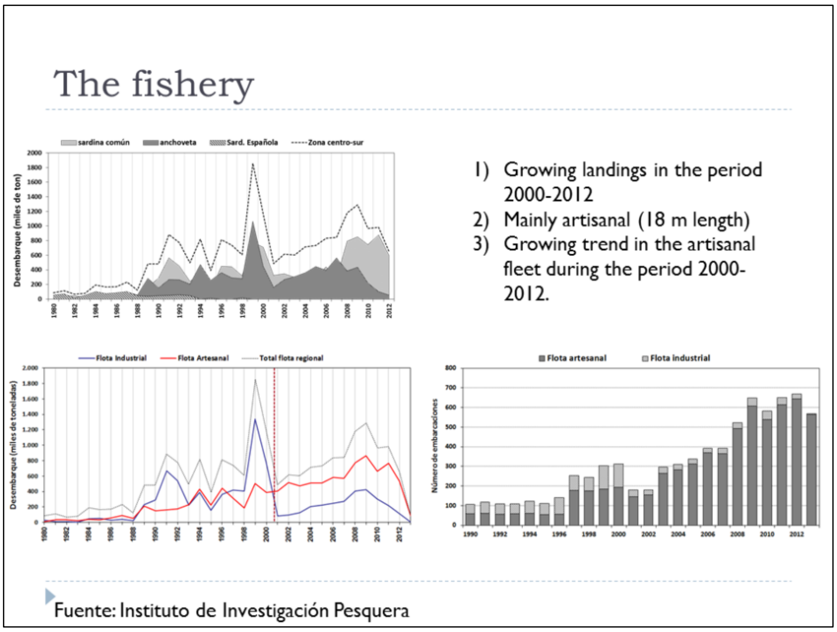



**Figure 3.** Annual catches of Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) off the coast of central Chile from 1990 to 2013 (Appendix 6.4, Cubillos)

***Bay of Biscay Anchovy Fishery (Appendix 6.6, Ibaibarriaga)***

Anchovy (*Engraulis encrasicolus*) has been taken from the Bay of Biscay for centuries, mainly for human consumption. Historically, it has been a Spanish purse-seine fishery, but since the 1990s, the fishery has also involved French pair-trawlers and purse-seiners. Annual catch peaked at ~80,000 t in 1965, with catches varying between 20,000 t and 40,000 t during the 1990s (Figure 4). The fishery was closed from 2005 to 2010. Recently, catches have ranged from 10,000 t to 15,000 t, and harvest control rules are used to set the TAC.

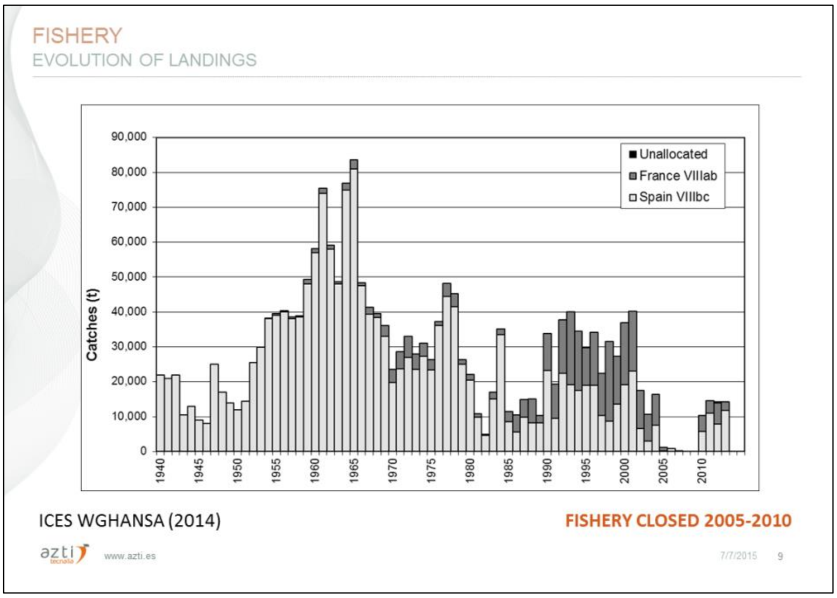



**Figure 4.** Annual catches of Anchovy (*Engraulis encrasicolus*) from the Bay of Biscay 1940 to 2013 (Appendix 6.6, Ibaibarriaga)

***Atlantic Iberia Sardine and Horse Mackerel Fisheries (Appendix 6.7, Angelico)***

Portuguese and Spanish vessels take Iberian Sardine (*Sardina pichardus*) from the eastern North Atlantic Ocean off Iberia. Total catches have declined from over 200,000 t in the 1980s to less than 60,000 t in 2013 (Figure 5). The Portuguese fishery is certified by the Marine Stewardship Council (MSC) and comprised of ~130 vessels of 12 to 23 m in length. The entire catch is destined for human consumption. Sardine make up 76% of total landings, with by-catch including Chub Mackerel (*Scomber colias*), Horse Mackerel (*Trachurus trachurus*) and Anchovy (*E. encrasicolus*).

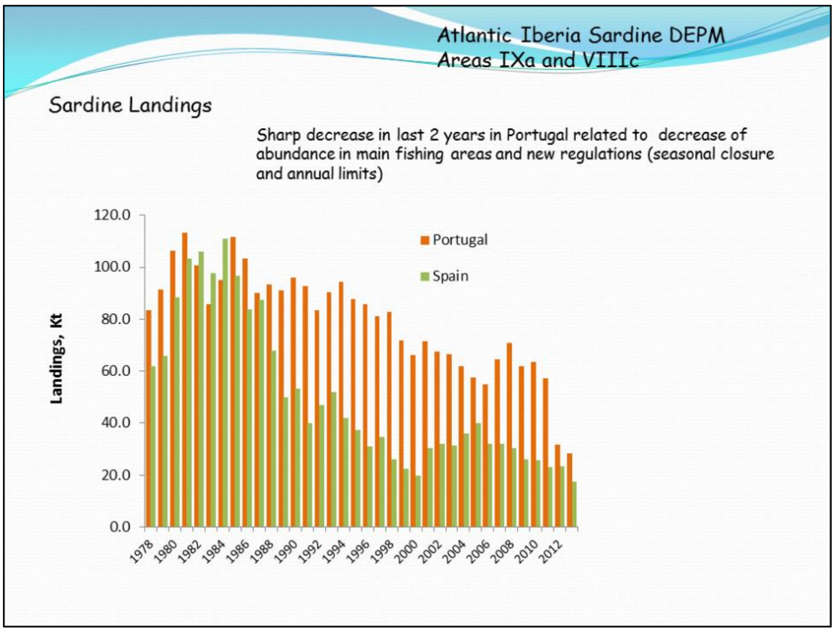



**Figure 5.** Annual catches of Iberian Sardine (*Sardina pichardus*) from the eastern North Atlantic Ocean from 1978 to 2013 (Appendix 6.7, Angelico)

Horse Mackerel is taken off Iberia by Portuguese bottom trawlers and purse-seine vessels. The total catch peaked at ~ 80,000 t in the mid-1970s, and the current annual catch is ~15,000 t taken by purse-seining and ~15,000 t taken by bottom trawling (Figure 6).

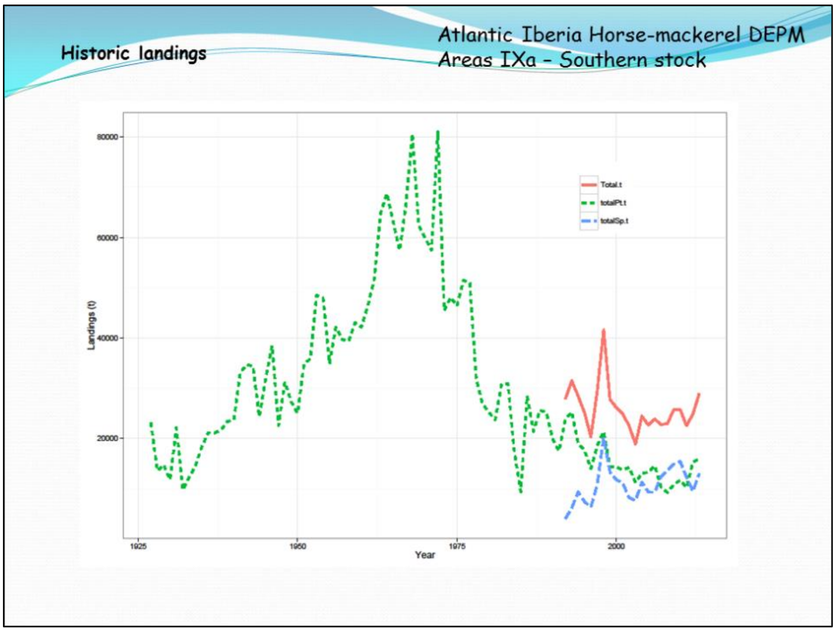



**Figure 6.** Annual catches of Iberian Horse Mackerel (*Trachurus trachurus*) from the eastern North Atlantic Ocean (Appendix 6.7, Angelico)

***European Mackerel Fishery (Appendix 6.8, van Damme)***

Since 1985, total catches in the European Mackerel (*Scomber scombrus*) fishery have ranged from about 400,000 t to 700,000 t (Figure 7). The population is comprised of three stocks: North Sea stock, West stock extending between Iceland and the Bay of Biscay, and Southern stock off Portugal and Spain. Significant catches (>10,000 t) are taken by at least 10 countries, with the majority of the catch taken by the United Kingdom, Norway and Iceland. Each of these countries landed >150,000 t of Mackerel in 2012. The fishery is managed under the European Union's Common Fisheries Policy.

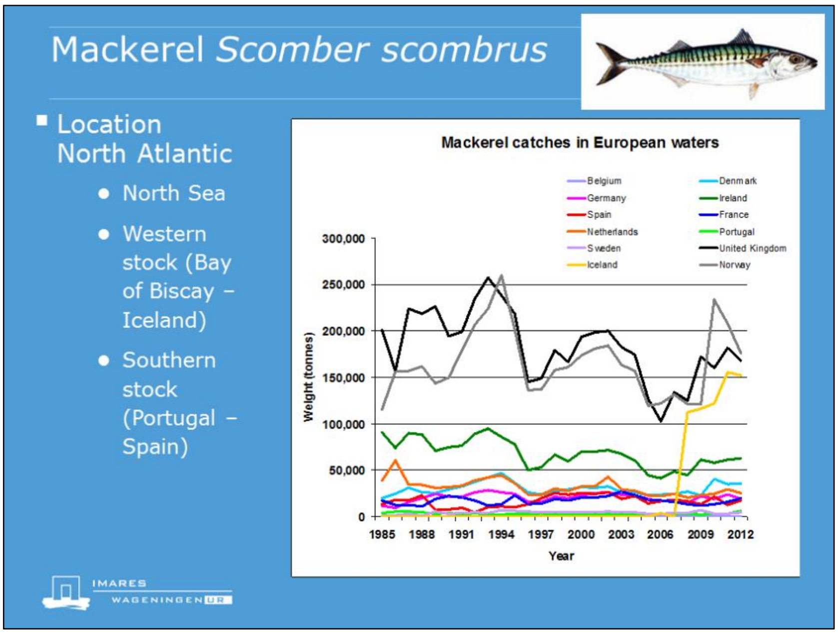



**Figure 7.** Annual catches of Mackerel (*Scomber scombrus*) from the North Atlantic Ocean from 1985 to 2012 (Appendix 6.8, van Damme)

## History of DEPM application and role in assessment process

### *South Australian Sardine Fishery (Appendix 6.2, Ward)*

The application of the DEPM in Australia was pioneered off Western Australia in the 1990s and has been applied off South Australia since 1995. Historically, annual estimates of spawning biomass (Figure 8) have been used directly to set TACs, with robust estimates of spawning biomass obtained since 1998. More recently, outputs from a population model are used to set TACs every second year (i.e. in years when DEPM surveys are not undertaken). TACs are set using a harvest strategy with explicit decision rules.

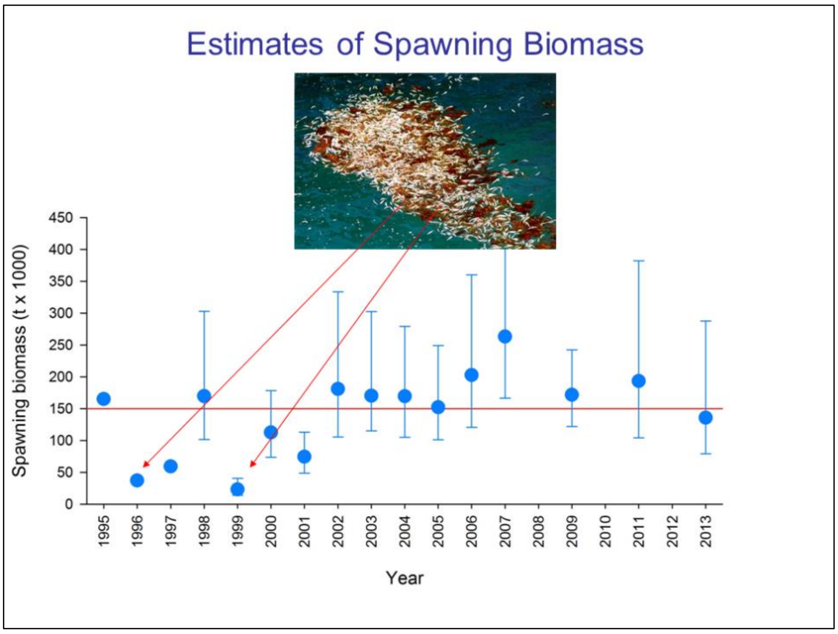



**Figure 8.** Historical estimates of spawning biomass of Australian Sardine (*Sardinops sagax*) off South Australia from 1995 to 2013. The red line is the target reference point (Appendix 6.2, Ward)

### *Californian Sardine Fishery (Appendix 6.3, Lo)*

The DEPM was developed for Northern Anchovy (*Engraulis mordax*) off California in the 1980s (Lasker 1985). Eggs of Pacific Sardine (*Sardinops sagax*) were also found in plankton samples during this period. Research surveys to estimate spawning biomass of Pacific Sardine using DEPM were undertaken in the late 1980s. Since 1994, a DEPM survey coupled with the California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey has been undertaken annually. Spawning biomass from the DEPM is the longest fishery-independent biomass index for Pacific Sardine. Two additional time series are now available: aerial surveys off the Pacific North-west (Oregon-Washington) since 2009; and acoustic surveys off California since 2011. Biomass estimates are incorporated into a stock assessment model, and harvest control rules are used to set the TAC (Figure 9). There are no ITQs.

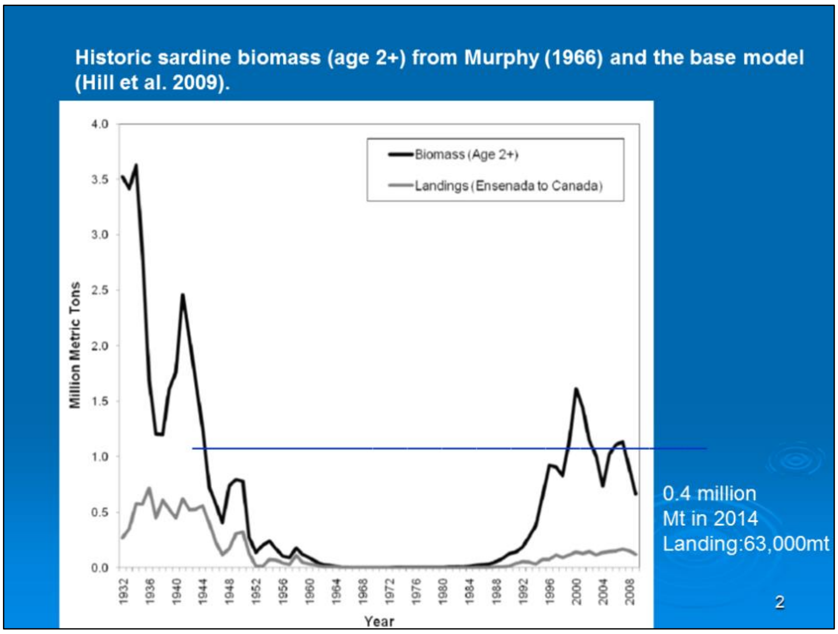



**Figure 9.** Historical estimates of adult biomass of Pacific Sardine (*Sardinops sagax*) off the west coast of North America from 1992 to 2008 (Appendix 6.3, Lo)

### *Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)*

The DEPM was applied to Common Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) off Chile in 2002 and has been conducted annually since then (except in 2006, due to logistical constraints). Estimates of spawning biomass are incorporated into an age-structured stock assessment model that also includes fishery-dependent information (catch, length/age structure, fishing effort) and acoustic surveys for Sardine recruitment and Anchovy total biomass (Figure 10). An explicit management procedure is used to determine the Total Biological Catch (TBC).

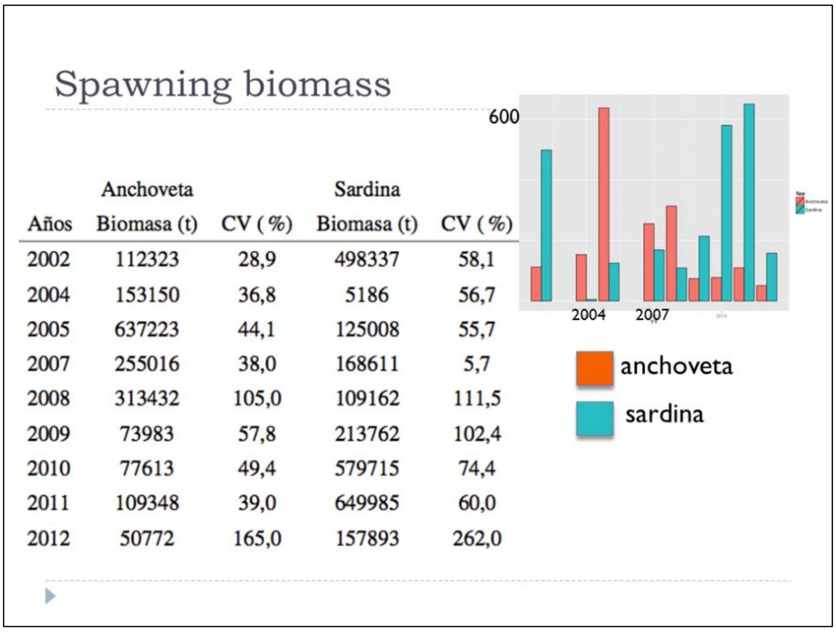



**Figure 10.** Historical estimates of spawning biomass of Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) off the coast of central Chile from 2002 to 2013 (Appendix 6.4, Cubillos).

***Bay of Biscay Anchovy Fishery (Appendix 6.6, Ibaibarriaga)***

In the Bay of Biscay, DEPM surveys of Anchovy have been conducted annually since 1987 (except in 1993). The first DEPM applications followed the methodology as described in Parker (1980) and Lasker (1985). However, several improvements were gradually made over time. The main objective of the surveys is to provide direct estimates of the state of the stock (spawning stock biomass and population age structure). Outputs from DEPM and acoustic surveys are inputs to a Bayesian state-space model (Figure 11). TACs are set using a harvest control rule; 90% of the TAC is allocated to Spain and 10% to France.

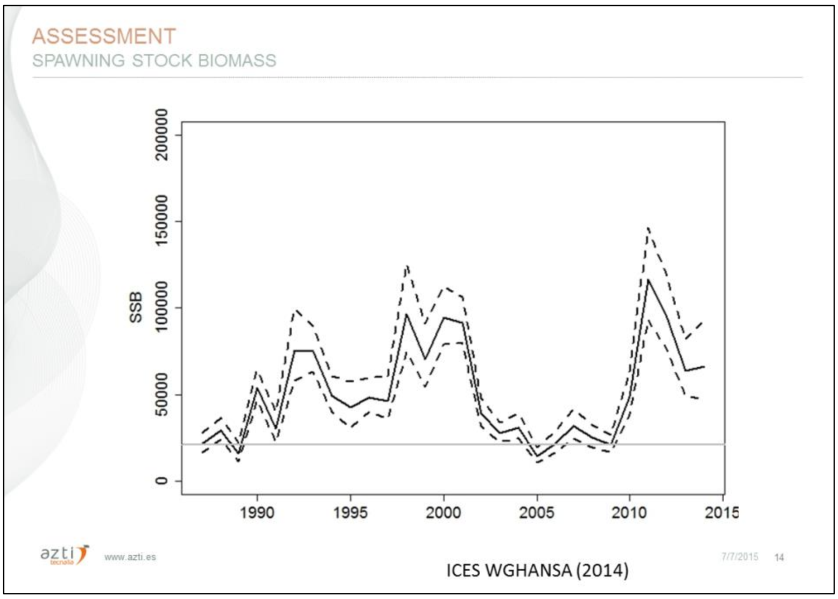



**Figure 11.** Historical estimates of spawning stock biomass of Anchovy (*Engraulis encrasicolus*) in the Bay of Biscay (Appendix 6.6, Ibaibarriaga)

***Atlantic Iberia Sardine and Horse Mackerel Fisheries (Appendix 6.7, Angelico)***

The DEPM was first applied to Atlantic Iberian Sardine (*Sardina pilchardus*) by Portugal and Spain in 1988. In 1990, only Spain carried out a survey. In 1997 and 1999, both countries organised surveys, which were coordinated informally. From 2000 onwards, methodological and analytical developments and effective coordination have been undertaken under the auspices of ICES Study/Working Groups. Estimates of spawning biomass are produced triennially and used in assessment modelling. The Sardine assessment model is age-based and assumes a single area, single fishery, yearly season and combined genders. Input data include catch (in biomass), age composition of the catch, total abundance (in numbers) and age composition from an annual acoustic survey and spawning-stock biomass estimates from the triennial DEPM survey (Figure 12).

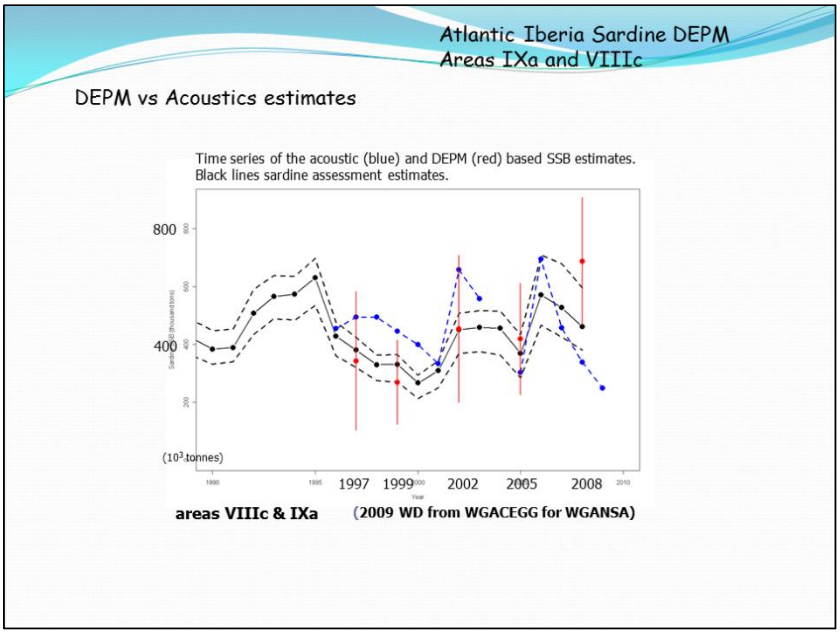



**Figure 12.** Historical estimates of spawning stock biomass of Iberian Sardine (*Sardina pichardus*) from the eastern North Atlantic Ocean (Appendix 6.7, Angelico)

Annual egg production surveys were conducted for Atlantic Iberian Horse Mackerel (*Trachurus trachurus*) in 1995. The DEPM was first applied to Atlantic Iberian Horse Mackerel in 2007 and reapplied in 2010 and 2013. Validation of egg identifications has been a significant challenge due to the presence of similar species in the area (*T. mediterraneus* and *T. picturatus*). Methods for estimating spawning fraction are still a work in progress (Figure 13).

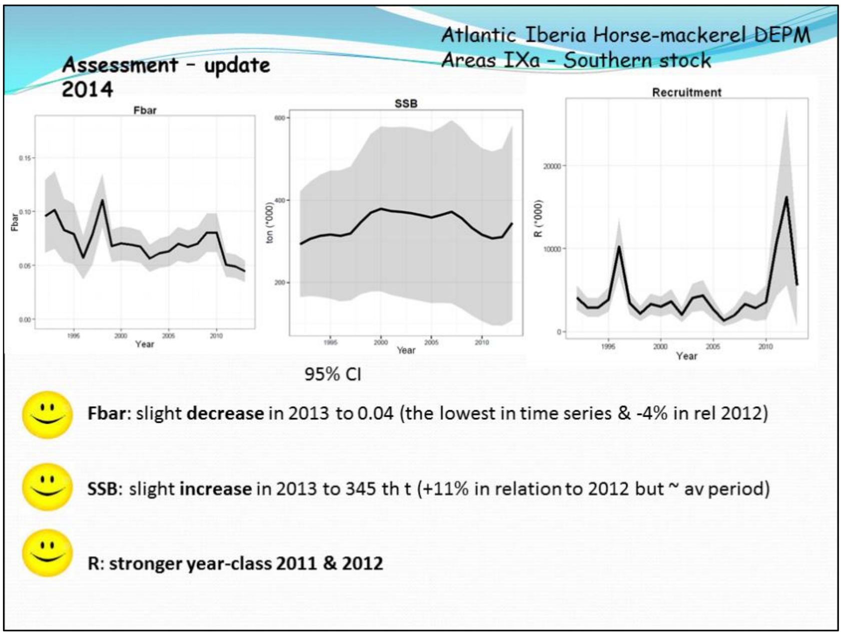



**Figure 13.** Historical estimates of spawning stock biomass of Atlanto-Iberian Horse Mackerel (*Trachurus trachurus*) from the eastern North Atlantic Ocean (Appendix 6.7, Angelico)

***European Mackerel Fishery (Appendix 6.8, van Damme)***

The annual egg production method (AEPM) has been applied to European Mackerel (*Scomber scombrus*) triennially since 1977. Surveys are conducted by nine countries, involve ten research institutes and 17 cruises (341 days at sea). Results are incorporated into a stock assessment model that was updated in 2014 (Figure 14). The suitability of the AEPM for European Mackerel has been questioned due to growing evidence that the species is an indeterminate spawner, and annual fecundity has been miscalculated. In 2013, surveys were conducted to compare the AEPM and DEPM. Application of the DEPM to European Mackerel is still in the developmental stage.

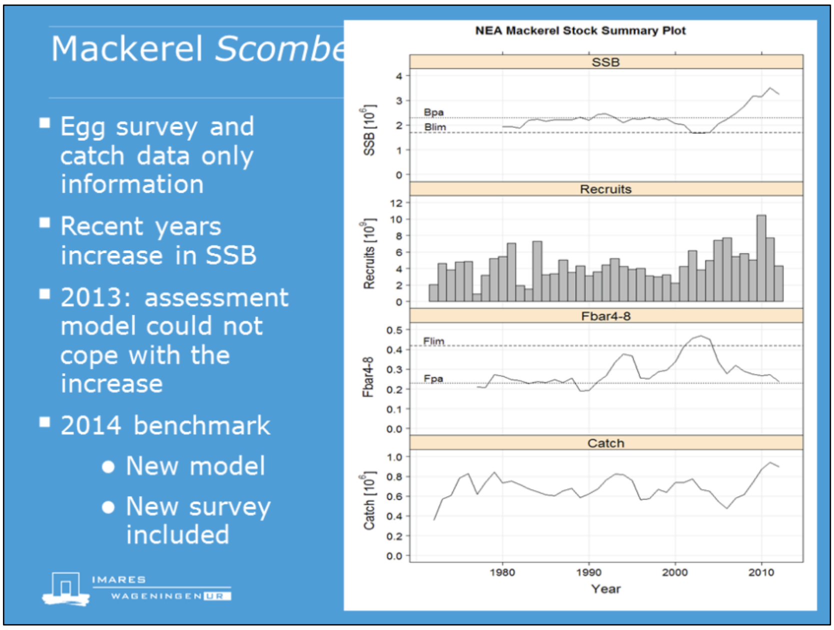



**Figure 14.** Historical estimates of adult biomass of Mackerel (*Scomber scombrus*) from the North Atlantic Ocean (Appendix 6.8, van Damme)

## Sampling design – egg surveys

***South Australian Sardine Fishery (Appendix 6.2, Ward)***

Egg surveys for the SASF have largely been undertaken as predetermined surveys designed to cover the historical and likely spawning area (Figure 15). A Continuous Underway Egg Sampler (CUFES) has been used as an adaptive sampling tool in surveys conducted since 2014. This followed a survey in 2013 when spawning occurred outside the historical survey area, and the spawning area was not fully covered. In the SASF, sampling intensity is relatively high (transects 15 nm apart; stations 5 nm apart). The survey area is stratified *post-hoc* into positive and negative strata based on the presence/absence of eggs in CalCOFI Vertical Egg Tow (CalVET) samples.

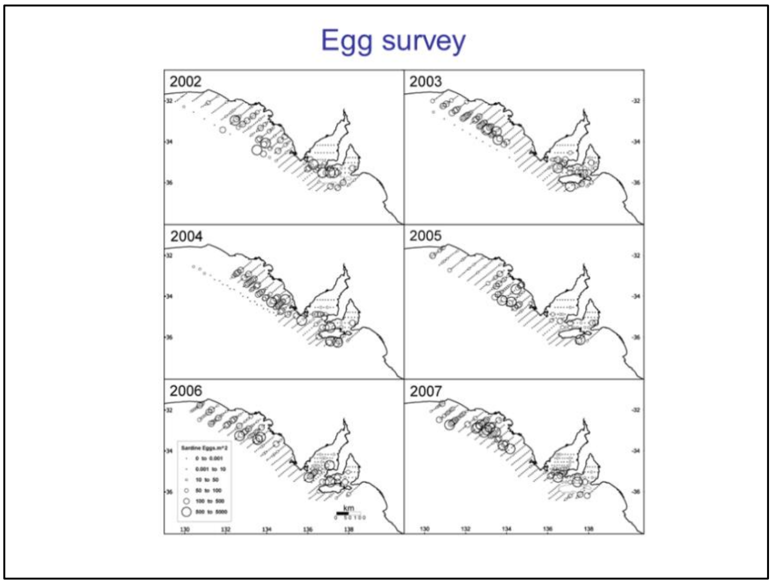



**Figure 15.** Plankton surveys conducted for Australian Sardine (*Sardinops sagax*) off South Australia from 2002 to 2007 (Appendix 6.2, Ward)

### *Californian Sardine Fishery (Appendix 6.3, Lo)*

In 1986 to 1988 and 1994, plankton samples were collected from predetermined sites along the southern California coastline. Since 1997, sampling has been adaptive, with CUFES used to identify areas of high egg density. Baseline sampling intensity is relatively low (Figure 16). Sampling intensity is increased when egg abundance is >1 egg.min$^{-1}$ in CUFES. Surveys were extended into Oregon and Washington in 2010 to 2012. However, the current survey covers Californian waters only. The survey is post-stratified into areas of high and low density. An age-structured population model is used to estimate total spawning biomass.

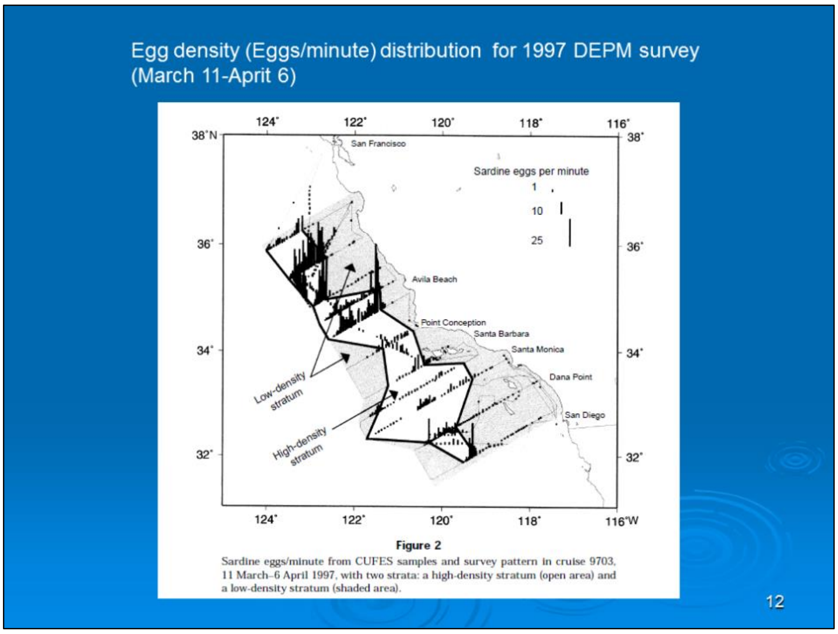



**Figure 16.** Egg densities of Pacific Sardine (*Sardinops sagax*) off southern California in 1997 (Appendix 6.3, Lo)

### *Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)*

Off Chile, a stratified sampling design has been applied to collect egg samples from two independent strata (Central and South sectors) using paired tows of vertical egg nets (Pairovet: 0.05 $m^2$ area, 25 µm mesh). The egg abundance in one of the Central stratum has had much year to year variability for both species, inflating the variance of initial egg production ($P_o$). The other stratum (South) is a recurrent spawning site, and $P_o$ estimates are usually more precise. Since 2007, transects are separated by 5 miles and stations are 4 miles apart (Figure 17).

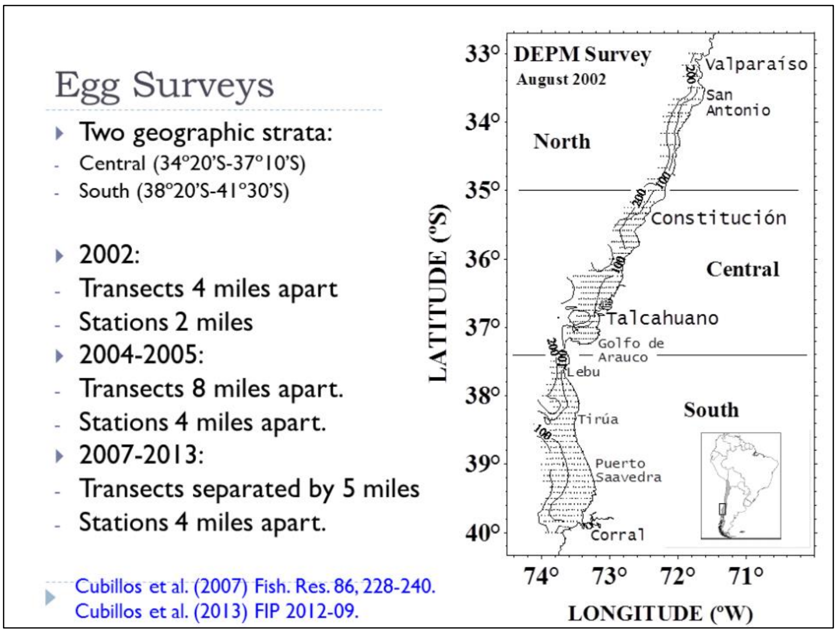



**Figure 17.** Egg surveys for Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) off the coast of Chile in 2002 (Appendix 6.4, Cubillos)

### *Bay of Biscay Anchovy Fishery (Appendix 6.6, Ibaibarriaga)*

The survey method used in the Bay of Biscay Anchovy Fishery is adaptive systematic sampling using Pairovet (0.150 mm mesh) to a maximum depth of 100 m or 5 m above bottom. Transects are perpendicular to the coast and 15 nm apart; stations are 3 nm apart. In areas of high egg abundance, transects are 7.5 nm apart. Flow-meters are used to detect clogging. A CUFES is deployed at a depth of 3 m with a mesh size of 350 µm, and samples are checked immediately. When there are no eggs in six consecutive stations on the transect sampling is stopped (Figure 18).

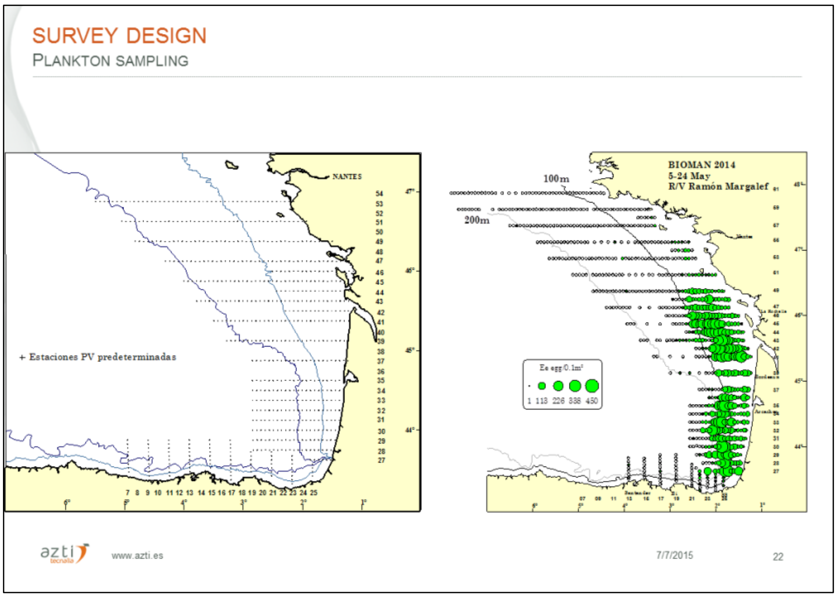



**Figure 18.** Survey design and egg densities of Anchovy (*Engraulis encrasicolus*) in the Bay of Biscay during 2014 (Appendix 6.6, Ibaibarriaga)

### *Atlantic Iberia Sardine and Horse Mackerel Fisheries (Appendix 6.7, Angelico)*

Atlantic Iberian Sardine surveys are conducted using a CalVET net at pre-determined sites (transects 8 nm apart and 3 or 6 nm between stations). Sampling intensity is increased in areas of high egg abundance based on data from CUFES. Sampling area is divided into positive and negative strata based on presence/absence of eggs (Figure 19).

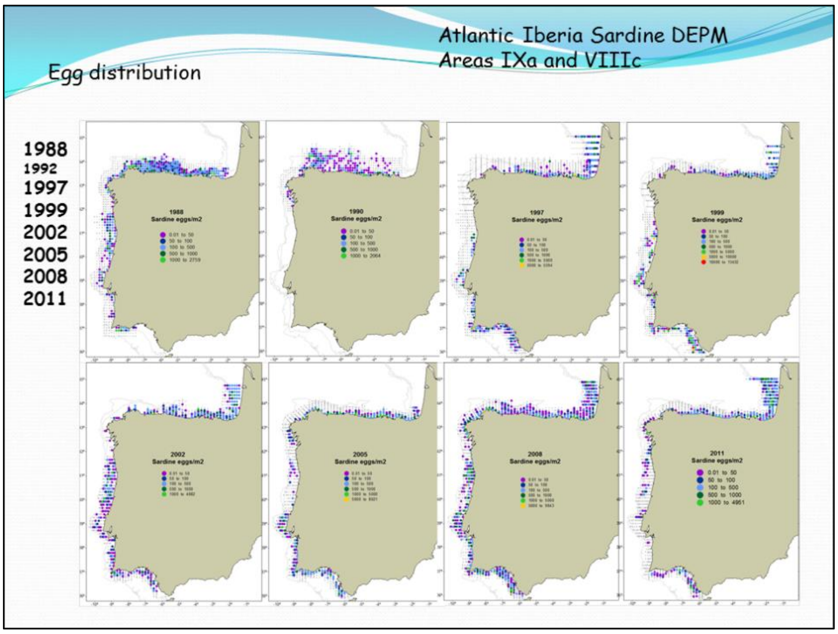



**Figure 19.** Egg distributions of Iberian Sardine (*Sardina pichardus*) in the eastern North Atlantic Ocean (Appendix 6.7, Angelico)

The approach taken for surveys of Atlantic Iberian Horse Mackerel (*Trachurus trachurus*) is similar to that for Atlantic Iberian Sardine. Transects are 10 nm apart, and stations are 3 or 6 nm apart (Figure 20). Samples are taken with a CaVET net. The main challenge for Atlantic Iberian Horse Mackerel is to cover the entire spawning area at an adequate resolution without compromising the assumption of synopticity.

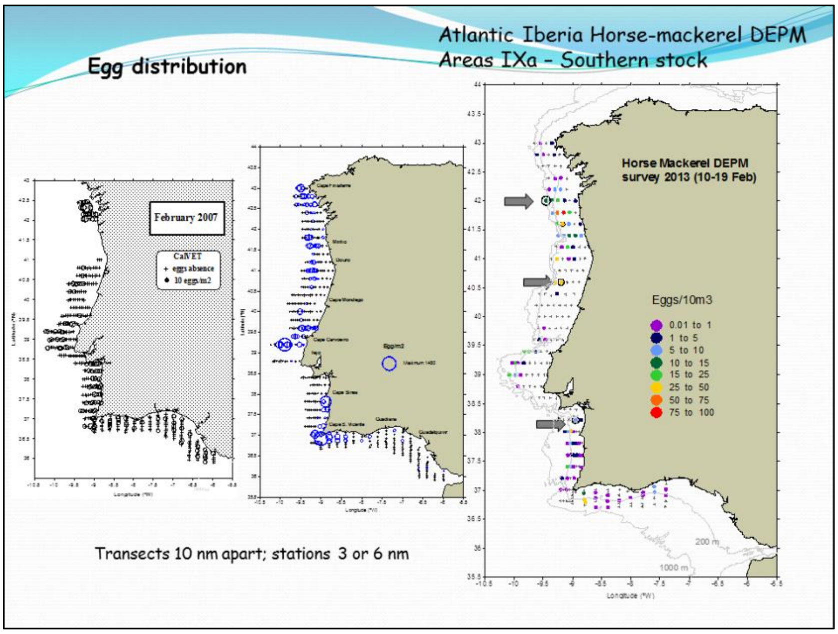



**Figure 20.** Egg distributions of Iberian Horse Mackerel (*Trachurus trachurus*) in the eastern North Atlantic Ocean (Appendix 6.7, Angelico)

***European Mackerel Fishery (Appendix 6.8, van Damme)***

Transects for the survey of Atlantic Mackerel (*Scomber scombrus*) are orientated east to west (Figure 21). A variety of sampling methods have been used that include Pairovet, bongo nets, and Gulf VII (high speed sampler: 4-5 knots). Tows are made as a double oblique haul to the bottom or a maximum depth of 200 m. Oblique tows are used with the CTD and flow metres.

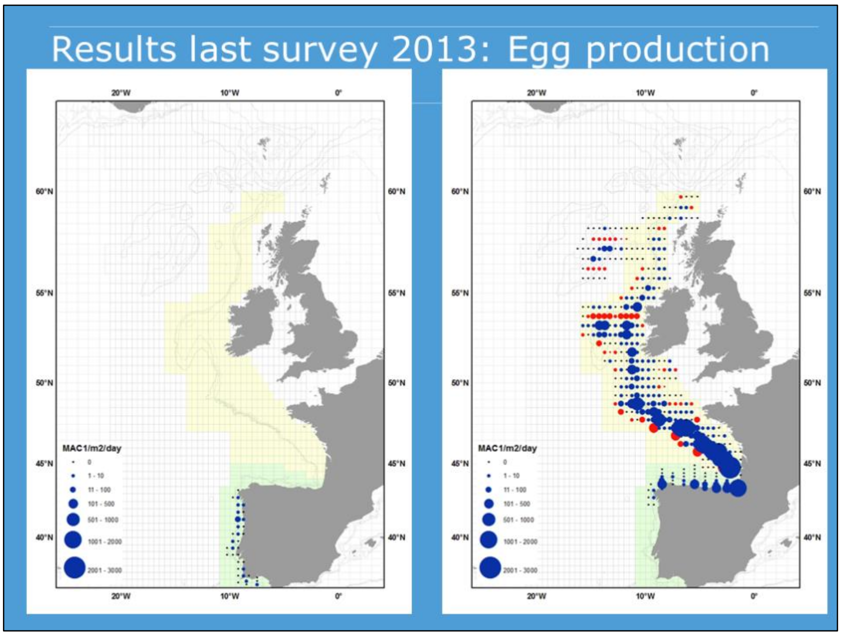



**Figure 21.** Egg distribution of Mackerel (*Scomber scombrus*) in the North Atlantic Ocean during 2013 (Appendix 6.8, van Damme)

## Estimating egg production

***South Australian Sardine Fishery (Appendix 6.2, Ward and 6.9, Carroll)***

In the SASF, the linear version of exponential egg mortality model (lognormal regression) has been used to estimate egg production (Figure 22). Egg mortality is estimated annually. For Australian Sardine off South Australia, the use of lognormal regression has been justified on the basis that the model better fits strongly over-dispersed egg density data (e.g. lower CVs). Lognormal regression provides logically consistent and more precautionary estimates of $P_0$ than the traditional exponential model and generalised linear models (GLMs) of untransformed data.

A model relating egg development rate to temperature has not been developed for Sardine in Australian waters. Eggs have been assigned approximate ages based on descriptions and temperature-development keys in White and Fletcher (1996). Peak spawning time and the modal age of each egg stage are estimated for three temperature ranges (< 19$^o$C, 19–20$^o$C, > 20$^o$C) using kernel density smoothing (Figure 23). Rates of egg development are similar to those described by Lo et al. (1985).

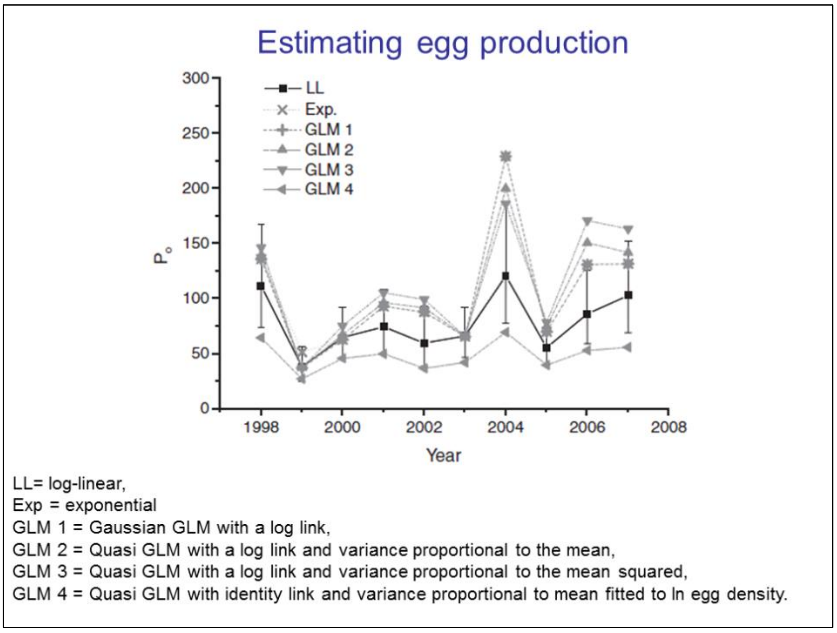



**Figure 22.** Estimates of egg production of Australian Sardine (*Sardinops sagax*) off South Australia using five different models (Appendix 6.2, Ward)

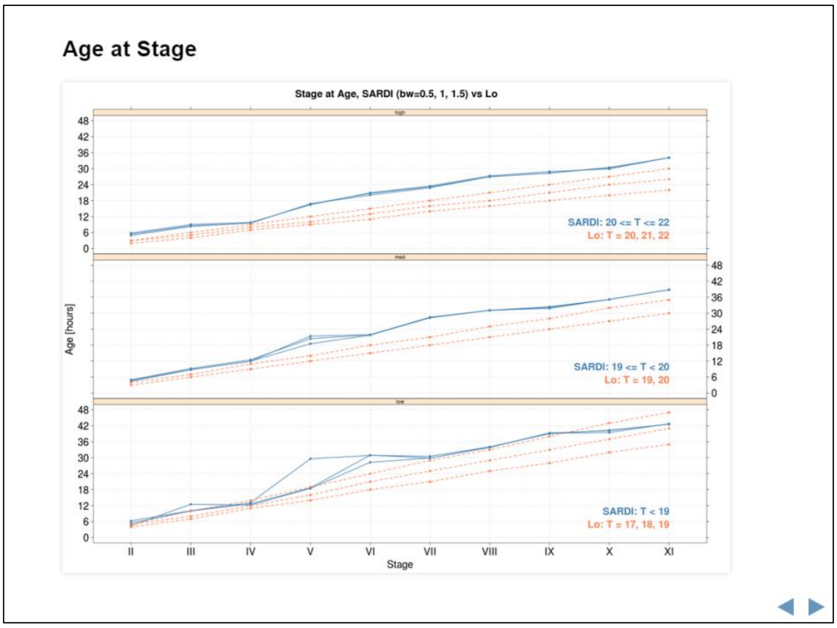
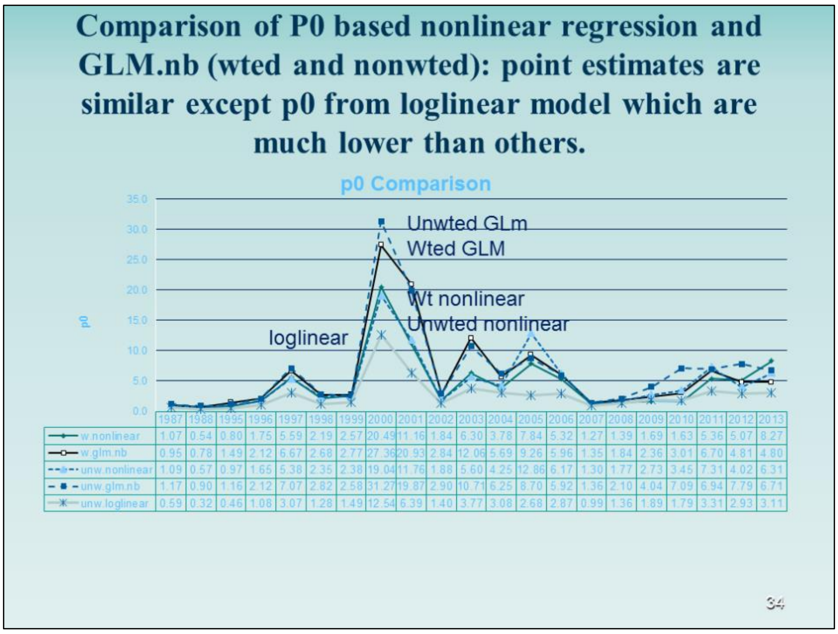



**Figure 23.** Estimates of egg age for each stage of Australian Sardine (*Sardinops sagax*) egg off South Australia compared to estimates of egg age derived experimentally by Lo et al. (1985). (Appendix 6.9, Carroll)

***Californian Sardine Fishery (Appendix 6.3, Lo)***

In the USA, weighted non-linear least squares regression is used to estimate egg production and mortality. Egg mortality is estimated annually (Figure 24). Densities of yolk sac larvae obtained with a bongo net are also used to estimate mortality (this requires ages to be assigned). Weightings applied are 1/SD for each 1 day age group and SD for each yolk sac larvae from CalVET and bongo nets, respectively. Comparisons of estimates of egg production obtained from (i) non-linear regression (weighted and unweighted), (ii) GLM with a negative binomial distribution and link function (weighted and unweighted) and (iii) log-linear regression indicate that estimates of $P_0$ from lognormal regression are too low. Notably, estimates of $P_0$ from the unweighted GLM had the lowest CV (not including the log-linear model), and it is recommended that a simulation to identify the most suitable method for estimating $P_0$ should be performed. Egg ages were estimated from temperature-development experiments by Lo (1985).




| | 1987 | 1988 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| w.nonlinear | 1.07 | 0.54 | 0.80 | 1.75 | 5.59 | 2.19 | 2.57 | 20.49 | 11.16 | 1.84 | 6.30 | 3.78 | 7.84 | 5.32 | 1.27 | 1.39 | 1.69 | 1.63 | 5.36 | 5.07 | 8.27 |
| w.glm.nb | 0.95 | 0.78 | 1.49 | 2.12 | 6.67 | 2.68 | 2.77 | 27.36 | 20.93 | 2.84 | 12.06 | 5.69 | 9.26 | 5.96 | 1.35 | 1.84 | 2.36 | 3.01 | 6.70 | 4.81 | 4.80 |
| unw.nonlinear | 1.09 | 0.57 | 0.97 | 1.65 | 5.38 | 2.35 | 2.38 | 19.04 | 11.76 | 1.88 | 5.60 | 4.25 | 12.86 | 6.17 | 1.30 | 1.77 | 2.73 | 3.45 | 7.31 | 4.02 | 6.31 |
| unw.glm.nb | 1.17 | 0.90 | 1.16 | 2.12 | 7.07 | 2.82 | 2.58 | 31.27 | 19.87 | 2.90 | 10.71 | 6.25 | 8.70 | 5.92 | 1.36 | 2.10 | 4.04 | 7.09 | 6.94 | 7.79 | 6.71 |
| unw.loglinear | 0.59 | 0.32 | 0.46 | 1.08 | 3.07 | 1.28 | 1.49 | 12.54 | 6.39 | 1.40 | 3.77 | 3.08 | 2.68 | 2.87 | 0.99 | 1.36 | 1.89 | 1.79 | 3.31 | 2.93 | 3.11 |

**Figure 24.** Estimates of egg production of Pacific Sardine (*Sardinops sagax*) off the west coast of North America from 1987 to 2013 using five different models (Appendix 6.3, Lo)

***Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)***

Two methods have been used in Chile to estimate $P_0$ (Figure 25) and egg mortality rate (Z) for stratified sampling designs where egg abundance is low and variable in one of the strata. One method is based on estimates of the ratio of egg abundance in the low-density stratum to egg abundance the high density stratum. Historically, a GLM with negative binomial and log-link has been applied. The second method is based on non-linear mixed effects models, where the strata are considered fixed effects and $P_0$ and Z as random effects. The precision of the conventional estimates of $P_0$ have been low, with coefficients of variation fluctuating between 0.28-1.65 and 0.06-2.62 for Anchovy and Sardine, respectively. Two ageing procedures are used: the original method of Lo (1985) and a multinomial model with a probabilistic distribution for spawning.

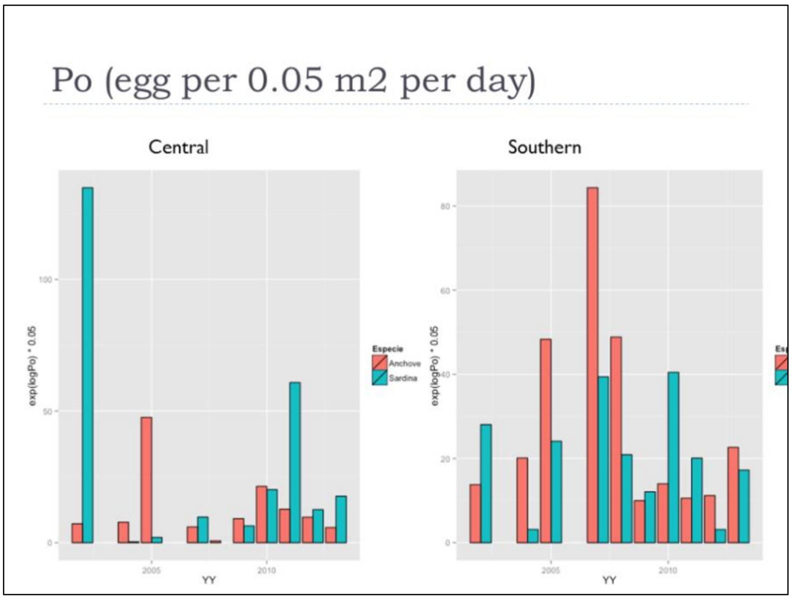



**Figure 25.** Estimates of egg production for Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) off the coast of central Chile (Appendix 6.4, Cubillos)

***Bay of Biscay Anchovy Fishery (Appendix 6.6, Ibaibarriaga)***

In the Bay of Biscay, the first DEPM applications followed the original methodology. However, several improvements have been gradually incorporated over time. A GLM has been used to estimate egg production since 2005 (Figure 26). A GLM that includes a negative binomial distribution and log-link with each station weighted according to its corresponding area has been used to estimate $P_0$ and Z. However, estimates of $P_0$ and Z depend on egg ageing, and the ageing depends on Z. An iterative approach to estimating $P_0$ has been proposed. New methods to estimate spawning fraction were established in 2013. A full revision of the historical time series of DEPM applications was presented to ICES in 2013 (Uriarte 2012).

A recommendation has been made to use estimates of mortality for all years combined rather than re-estimating mortality annually. The benefits of establishing spatially explicit estimates of Z have also been noted, as are the benefits of incorporating larval stages. A new model for overcoming some of these problems has been presented. The new model has several benefits that include: overcoming problems associated with estimation of Z and providing estimates of higher precision (Figure 27). A new egg ageing method has been developed, where eggs are classified into stages and daily cohorts according to a Bayesian ageing method (Bernal 2001, 2008; Ibaibarriaga et al. 2007).

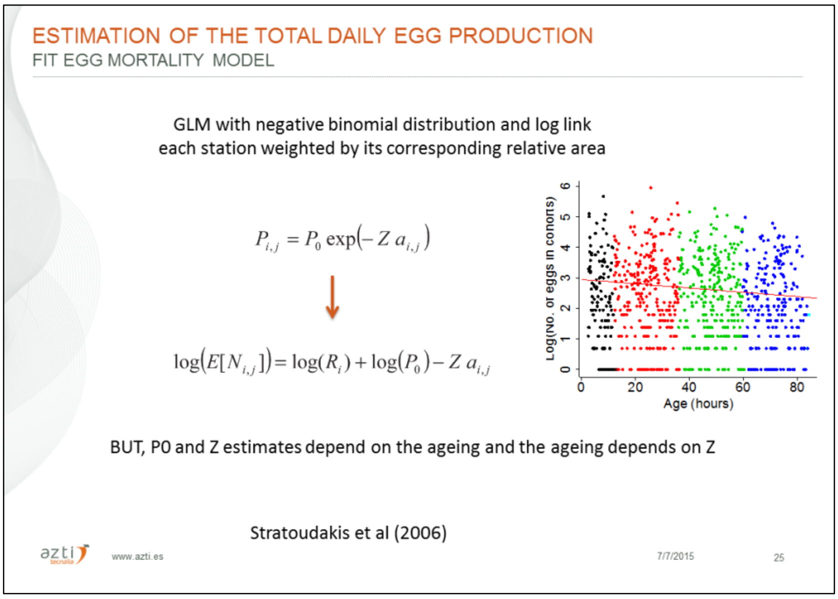



**Figure 26.** Estimates of egg production for Anchovy (*Engraulis encrasicolus*) in the Bay of Biscay (Appendix 6.6, Ibaibarriaga)

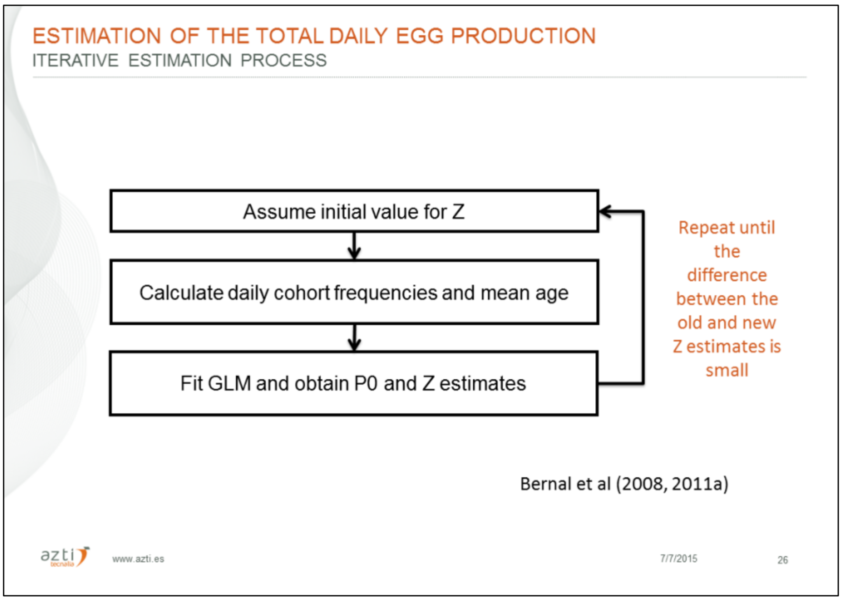



**Figure 27.** Iterative process for estimating of egg production for Anchovy (*Engraulis encrasicolus*) in the Bay of Biscay (Appendix 6.6, Ibaibarriaga)

***Atlantic Iberia Sardine and Horse Mackerel Fisheries (Appendix 6.7, Angelico)***

In the Atlantic Iberia Sardine fishery, improved methods have been developed for estimating Z and $P_0$ (Figure 28). Biased mortality estimates can arise from problems with surveying or difficulties fitting the mortality curve, particularly in relation to lack of observations at both tails of the egg distribution, and very young and very old eggs being poorly represented in plankton samples. In the presentation, reliability of mortality estimates per strata and for each year separately is discussed alongside a reanalysis of average mortality estimation obtained via the external mortality modelling approach described by Bernal et al. (2011). A mortality model using spatial and temporal strata is also described. Results from this model are compared to estimates of $P_0$ and Z obtained using traditional methods (Figure 28).

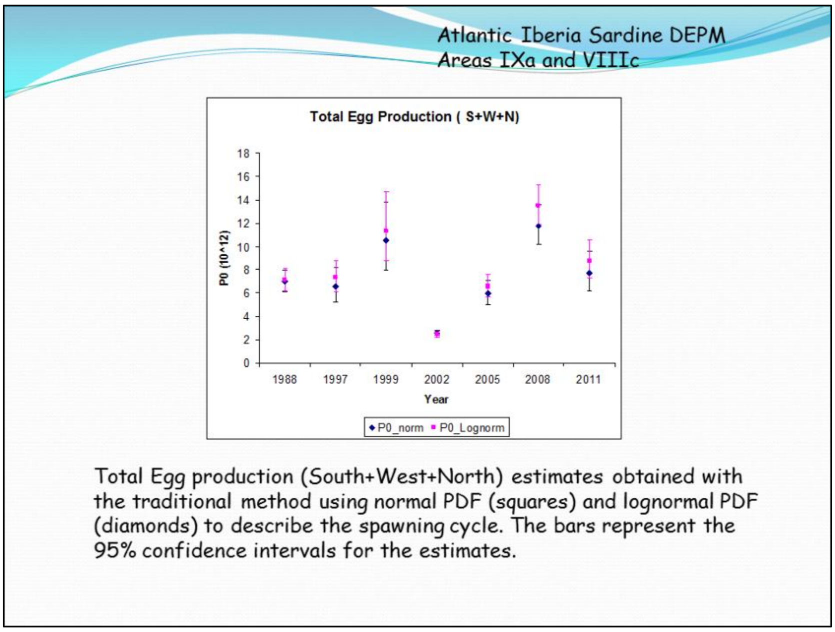



**Figure 28.** Estimating of egg production for Sardine (*Sardina pichardus*) in the eastern North Atlantic Ocean (Appendix 6.7, Angelico)

Traditional methods have been used to obtain estimates of the $P_0$ and Z for Atlantic Iberian Horse Mackerel.

***European Mackerel Fishery (Appendix 6.8, van Damme)***

New techniques for sorting (e.g. Spray method), measuring and counting (e.g. image analysis) eggs were described that, with further testing and development, have the potential to revolutionise current methods for processing samples.

## Adult parameters

***Spawning Fraction (Appendix 6.10, Ganias)***

The post-ovulatory follicles (POF) method for estimating spawning fraction was developed for northern Anchovy and over the last 35 years has been applied to numerous other species, usually without validation. Sources of bias include: (i) sampling (under- or over-sampling of spawning classes due to spawning behaviour, demography or lack of spawning periodicity; Figure 29); (ii) technical issues related to staging (incorrect identifications); (iii) ageing (inter- and intra-specific variation in absorption rates, assumption of daily synchronicity); and (iv) estimation (errors in numerator or denominator). Solutions to major issues include: (i) eliminate sampling bias by using techniques that sample populations representatively; (ii) reduce the potential for confusing different POF stages by sampling over limited time periods; and (iii) improve ageing of POFs through tank experiments and field observations (Appendix 6.10, Ganias).

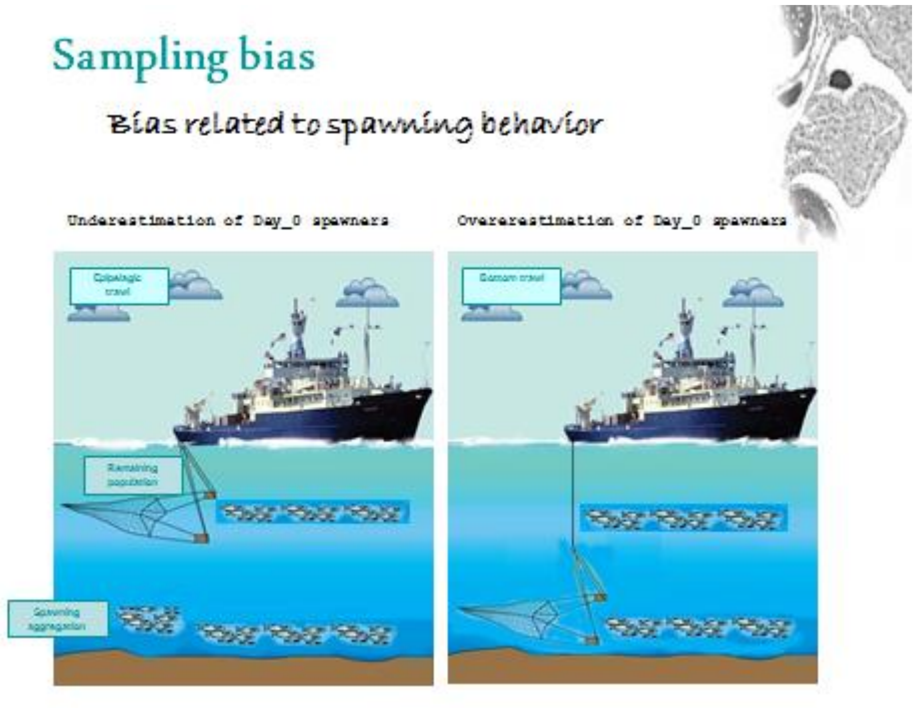
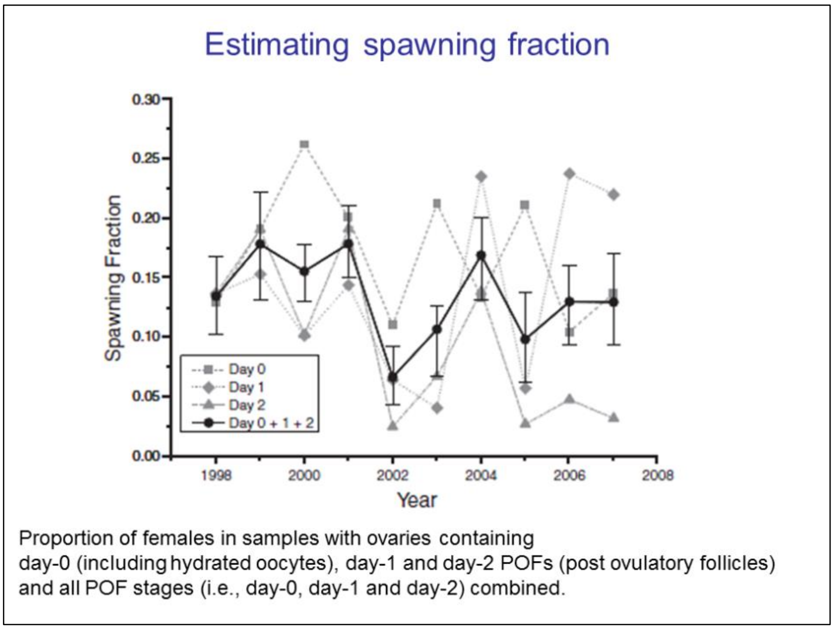



**Figure 29.** Bias in estimates of spawning fraction due to under or oversampling of spawning classes due to spawning behaviour (Appendix 3.1, Ganias).

***South Australian Sardine Fishery (Appendix 6.2, Ward)***

In South Australia, fishing is located inshore and typically targets relatively young fish, making commercial samples unsuitable for estimating adult parameters. In the SASF, adult samples are obtained using gillnets.

Estimates of spawning fraction are calculated from the average proportion of females in samples with ovaries containing day-0, day-1 and day-2 POFs (Figure 30).




Proportion of females in samples with ovaries containing day-0 (including hydrated oocytes), day-1 and day-2 POFs (post ovulatory follicles) and all POF stages (i.e., day-0, day-1 and day-2) combined.

**Figure 30.** Estimates of spawning fraction of Australian Sardine (*Sardinops sagax*) off South Australia calculated from average proportion of females in samples with ovaries containing day-0, day-1 and day-2 post-ovulatory follicles (POF) (Appendix 6.2, Ward)

***Californian Sardine Fishery (Appendix 6.3, Lo)***

In the USA, fishing is located inshore and targets young fish, making commercial samples unsuitable for estimating adult parameters. Mid-water trawls operated at night are used to collect adult samples. Spawning fraction is calculated from the average number of females with day-1 and day-2 POFs (Figure 31). Females with day-0 POFs are not included in the analyses, because they are under-represented in mid-water trawls.

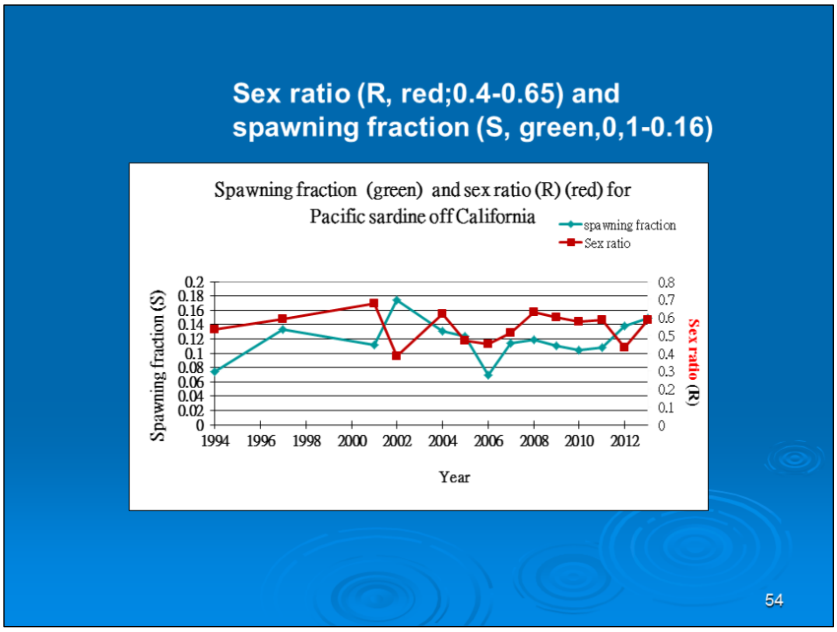



**Figure 31.** Estimates of spawning fraction of Pacific Sardine (*Sardinops sagax*) off the west coast of North America from 1994 to 2013 calculated from the average proportion of females in samples with ovaries containing day-1 and day-2 POFs (Appendix 6.3, Lo)

### *Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)*

Adult sampling is conducted simultaneously with an egg survey using four vessels in the Central Zone and four vessels in the South Zone (Figure 32). Samples are collected by purse-seining, mainly during the day. There is a target of 50 sets for each species in each stratum (Central and South). Numbers of adult fish per sample needed for estimating various parameters are: 120 fish for length frequency, 40 females for histology, 50 specimens for sex ratio by weight, and 50 hydrated females for batch fecundity. The spawning fraction is calculated as the proportion of females with day-1 POFs. The need is recognised for better estimates of spawning fraction by improved understanding of the degeneration rates of POFs.

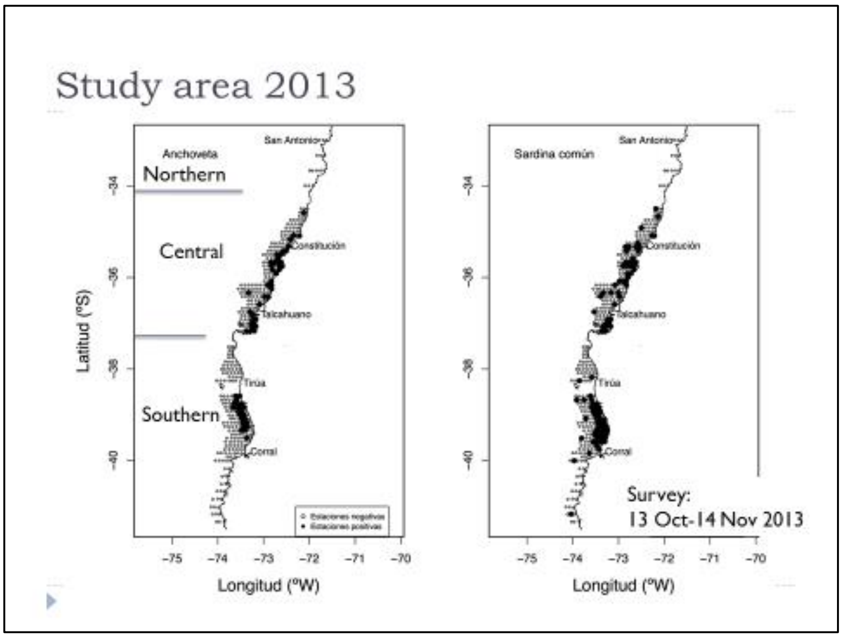



**Figure 32.** The three zones in the Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)

### *Bay of Biscay Anchovy Fishery (Appendix 6.6, Ibaibarriaga)*

Adult samples of Anchovy are collected by mid-water trawling. A range of options have been used that include: trawling from vessels used to collect plankton samples, using an accompanying vessel, and obtaining samples from the commercial fleet. Adult sampling coincides spatially and temporally with egg sampling. There is a random selection of 2 kg samples with a minimum of 1 kg or 60 anchovies being weighed, measured and sexed. A linear regression is used to estimate the relationship between total weight and gonad free weight, and average female weight is obtained for each sample. Sex ratio is calculated as the ratio between average female weight and sum of average female and male weights. Batch fecundity is estimated using the gravimetric method. A GLM with a gamma distribution and identity link is fitted and used to estimate batch fecundity for each sample. Since 2013, a new method has been used to estimate spawning fraction (Figure 33). Staging of the gonads and ageing are done separately. Ageing is done according to matrices based on historical samples and laboratory experiments. Spawning fraction is calculated from the mean proportion of females containing day-0 and day-1 POFs, with a correction for sampling bias if required. Estimates of spawning fraction obtained using the revised method (since 2013) are much high than those obtained using the traditional method.

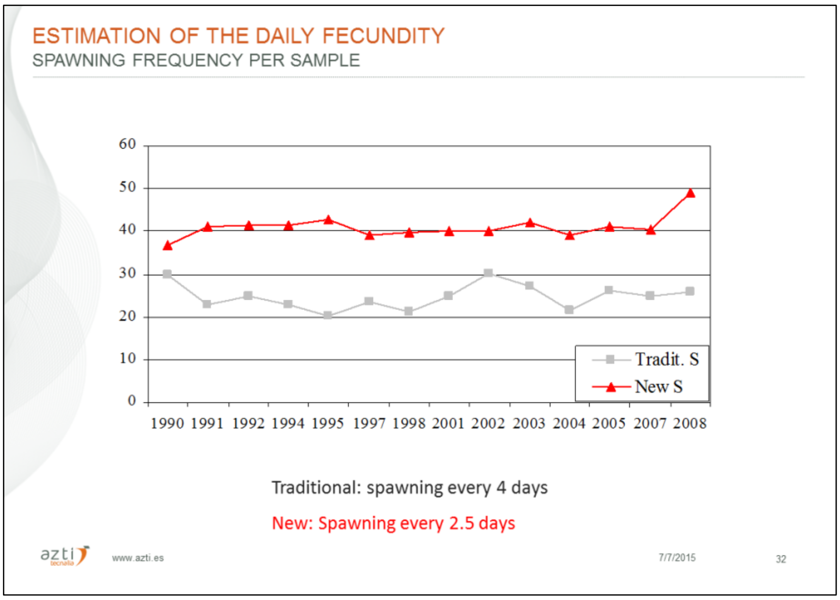



**Figure 33.** Estimates of spawning fraction of Anchovy (*Engraulis encrasicolus*) in the Bay of Biscay based on day-0 and day-1 POFs using both the traditional and new methods (Appendix 6.6, Ibaibarriaga)

***Atlantic Iberia Sardine and Horse Mackerel Fisheries (Appendix 6.7, Angelico)***

The type of sampling gear can affect estimates of adult parameters due to vertical segregation of a population and gear selectivity. Females with heavier ovaries and large males are close to the bottom and/or more available in bottom trawls. Mean female weight is higher in purse-seine samples, and spawning fraction is higher from bottom trawl samples. There is also subjectivity in ageing and staging of POFs. The most difficult parameter to estimate is spawning fraction based on the POF method, and, often has low precision and a higher potential for bias. The impacts of temperature on POF degeneration have not been fully evaluated to date. The use of hydrated females to estimate spawning fraction may introduce an additional bias. It is recommended that sample stratification be used when there are significant regional differences in adult parameters.

Atlantic Iberian Horse Mackerel samples are collected using demersal trawls. In 2013, length distributions varied among areas. Batch fecundity is estimated using the gravimetric method, and not the migrated nucleus method. Linear regression (GLM, negative binomial) is used to model the relationship between batch fecundity and ovary-free weight. Spawning fraction has not yet been estimated, and the degeneration rate of POFs is unknown. Future aims include developing a POF classification based on: (i) histomorphological and metrical (POF cross sectional area) criteria and (ii) time of sampling.

***Batch fecundity (Appendix 6.10, Ganias)***

The main problem associated with estimation of batch fecundity using gravimetric or volumetric method is that hydrated females are scarce, and their occurrence is limited in time and space. Alternatives include using tertiary oocytes and oocytes with migrated nuclei, but these cannot be applied to species with continuous oocyte distribution or those lacking an oil droplet. An automated method for counting hydrated oocytes through image analysis has been developed. Oocyte frequency distributions have also been used to estimate batch fecundity in females without hydrated oocytes. This approach increases the number of specimens that can be used to estimate spawning fraction (Appendix 6.10, Ganias)

***Molecular techniques for egg identification (Appendix 6.11, Saunders, 6.12, Steer and 6.13, Keane)***

A range of different techniques have been used and are being developed to identify eggs. These approaches are important in situations where egg identification is complicated by the presence of a large number of species with similar egg morphologies. Multiplex suspension bead arrays are being investigated for identification of multiple species in northern Australia, as well as investigating use of flow cytometer to count eggs (Appendix 6.11, Saunders). A snapper-specific molecular probe has been designed from a mitochondrial gene target (16s rRNA). This probe will be used via in-situ hybridization to identify snapper eggs from field collected plankton samples (Appendix 6.12, Steer). Mitochondrial DNA sequencing has been used for Blue Mackerel, Jack Mackerel and Redbait (Appendix 6.13, Keane).

## Harvest strategies (control rules)

***Harvest strategies (Appendix 6.15, Sloan)***

A harvest strategy is a framework that specifies pre-determined management actions in a fishery for defined species (at the stock or management unit level) necessary to achieve the agreed ecological, economic and/or social management objectives. The key elements of a harvest strategy are: (i) defined operational objectives for the fishery; (ii) indicators of performance related to the objectives; (ii) reference points for performance indicators; (iv) a statement defining acceptable levels of risk; (v) a monitoring strategy to collect data to assess performance; (vi) a process for conducting assessment of fishery performance; and (vii) decision control rules that control fishing catch or activity levels (Appendix 6.15, Sloan).

***South Australian Sardine Fishery (Appendix 6.16, Ward)***

The harvest strategy of the SASF is a tiered framework for setting catches in two zones (Gulfs and Outside). The three tiers allow for different levels of exploitation (up to 20%, 22.5% and 25%) based on different levels of information (risk/cost). Exploitation rates and catch levels are also adjusted to reflect the size of the spawning biomass in relation to limit and target reference points (Figure 34).

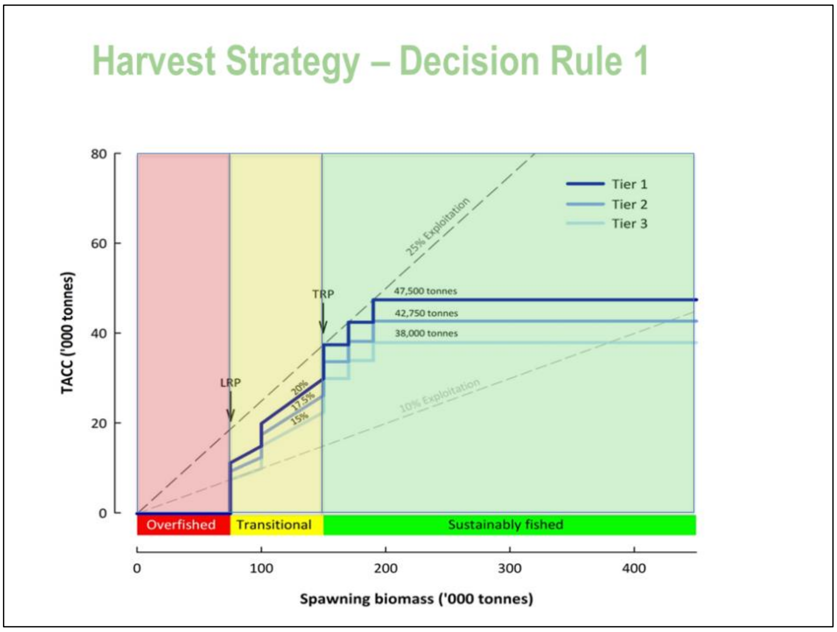



**Figure 34.** Harvest strategy for the South Australian Sardine Fishery (Appendix 6.16, Ward)

### *Californian Sardine Fishery (Appendix 6.17, Lo)*

The harvest control rules for the USA West Coast Pacific Sardine Fishery are based on stock biomass (Figure 35). There is a limit reference point or cut-off at 150,000 t. The harvest fraction is set at 5-20% or 10-20% based on the temperature and moderated by the portion of the biomass assumed to be in US waters (87%).

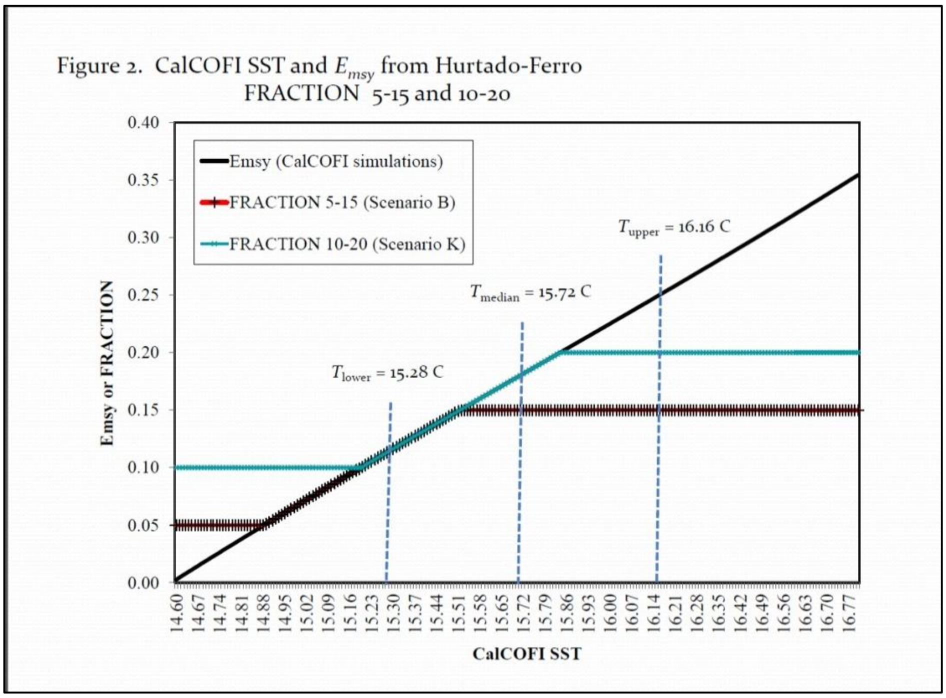



**Figure 35.** Harvest strategy for USA Pacific Sardine (*Sardinops sagax*) Fishery from 2014 (Appendix 6.17, Lo)

### *Chilean Sardine and Anchovy Fishery (Appendix 6.4, Cubillos)*

The TBC is determined by applying a target biological reference point (constant fishing mortality rate) to biomass estimates from the stock assessment model (Figure 36). The TBC is reviewed after the summer acoustic survey and may be reviewed again after the autumn acoustic survey. Maximum sustainable yield (MSY) is the management goal. A recovery plan must be established for over-exploited stocks. The quota for each species is allocated to fishing fleets, space-time factors and vessels (ITQ-like system). Landings are monitored to control catches.

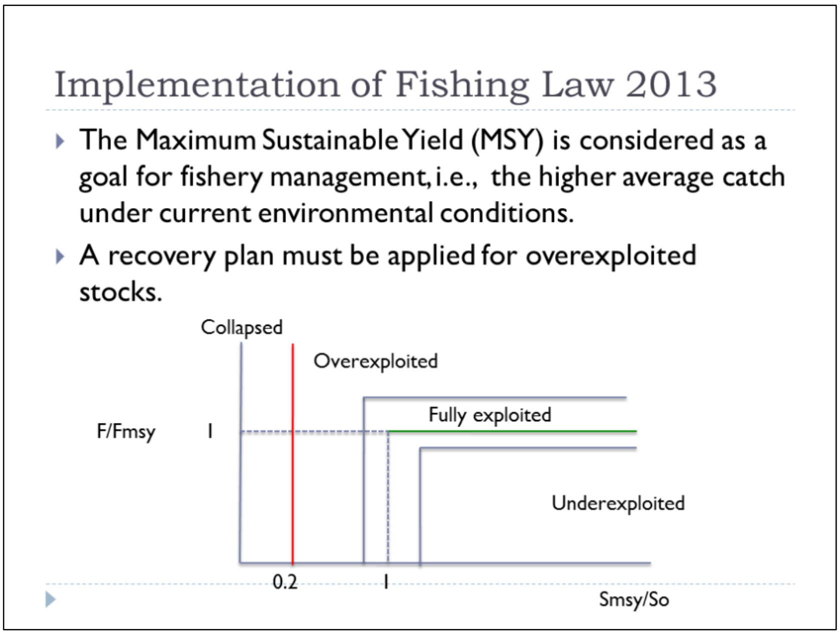



**Figure 36.** Harvest strategy for Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) off the coast of central Chile (Appendix 6.4, Cubillos)

***Bay of Biscay Anchovy Fishery (Appendix 6.18, Ibaibarriaga)***

A long term management plan for the Bay of Biscay Anchovy Fishery was proposed in 2009. Although this plan has not been officially implemented, it has been applied since 2009 (Figure 37). It is a constant harvest rate strategy with a limit reference point of 24,000 t. The minimum TAC is 7,000 t and the maximum TAC is 33,000 t. The TAC is allocated to Spain (90%) and France (10%). There is a closed season from December to February and daily catch limits on vessels.

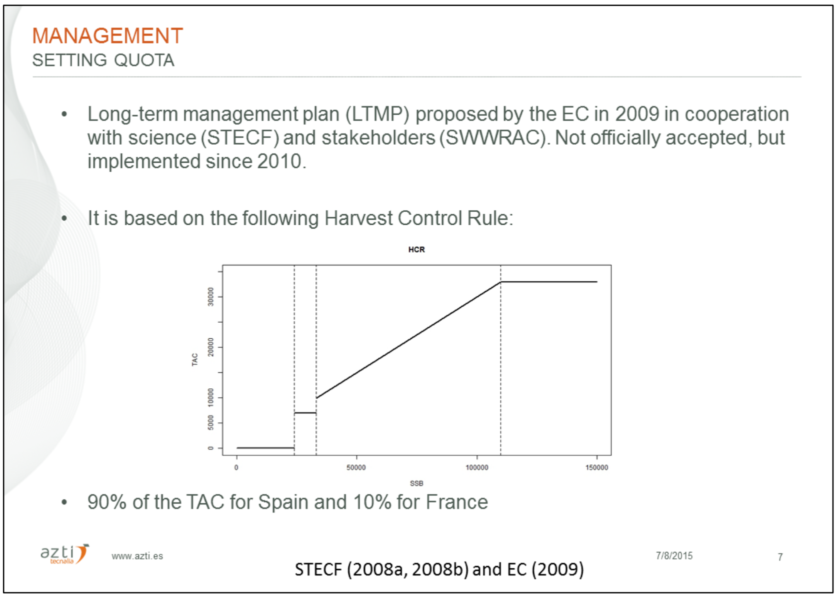



**Figure 37.** Harvest strategy for Anchovy (*Engraulis encrasicolus*) in the Bay of Biscay (Appendix 6.18, Ibaibarriaga)

***Atlantic Iberia Sardine and Horse Mackerel Fisheries (Appendix 6.19, Angelico)***

A management plan with ecological and socio-economic objectives was established for the Portuguese component of the Atlantic Iberia Sardine in 2010. It includes a harvest rule that is used to set the TAC for

Portugal and was agreed to by Spain in 2013 (implementation is in progress) (Figure 38). The TAC is set from estimates of biomass of age (year) 1+ fish. The limit reference point is 135,000 t, and the trigger reference point is 368,400 t. The target catch is 86,000 t. A size limit, input controls (net and mesh size) and area and seasonal closures are also used in the fishery.

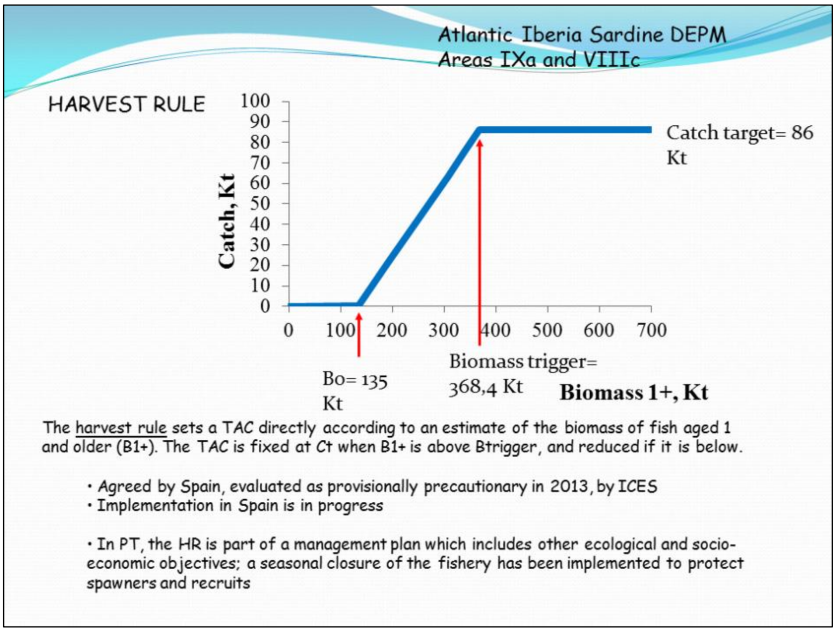



**Figure 38.** Harvest Strategy for Sardine (*Sardina pichardus*) in the eastern North Atlantic Ocean (Appendix 6.19, Angelico)

## Ecosystem effects

***Managing for ecosystem effects of fisheries for small pelagic species (Appendix 6.20, Smith)***

Findings of two studies on trophic impacts of fishing small pelagic species were reported: Marine Stewardship Council (MSC 2011) and Lenfest Study Group (2012). The MSC study used several ecosystem models to determine levels of fishing mortality of low trophic level species on other groups. The study suggested a default Target Reference Point (TRP) of 75% $B_0$ and Limit Reference Point (LRP) of half the TRP and not less than 20% $B_0$ (Smith et al. 2011). Higher or lower TRP could be set where it can be demonstrated that the level does not impact the abundance of more than 15% of other species/groups by >40% (compared to no fishing) or reduce the abundance of any other single species/group by >70%. The Lenfest study suggested that harvest strategies and management measures should ensure that there is a greater than 95%chance that fishing on forage fish will not deplete any dependent predator population to levels that would meet the International Union for Conservation of Nature (IUCN) "vulnerable" criteria. It is recommended that biomass should be greater than 74% $B_0$ to ensure that predators do not decline by more than 50% with a 95% probability of success.

***CCAMLR's ecosystem approach to managing fisheries on forage species: maintaining precaution (Appendix 6.21, Melbourne-Thomas)***

The Antarctic ecosystem is highly dependent on Krill (*Euphausia superba*). The TRP for Krill is 75% $B_0$ and the LRP is 20% $B_0$ with a probability of 0.1. There is considerable uncertainty regarding trends in Krill abundance, predator requirements and localised impacts. The spatial patterns in Krill harvesting and predator monitoring needed to meet CCAMLR's conservation objectives are unknown. Management units have been designed around land-based predators and their foraging ranges. An ecosystem monitoring program was established in the 1980s in response to expansion of the Krill fishery. The program was established to detect changes in Krill due to fishing, as well as to monitor effects on predators. Predator monitoring has been limited. There is increasing evidence of substantial retention of Krill in the main fishing locations. Fishery effects on population-level predator productivity include the proportion of fished species in diet, foraging performance (including foraging activity), reproductive success and population size (Constable 2001). Progress has been made in East Antarctica on regional-level assessment of predator performance and productivity. Challenges for the future include: (i) operationalising CCAMLR's objectives through feedback management; (ii) maintaining a level high confidence that conservation objectives will be achieved (high power) despite lack of data; and (iii) evaluating management strategies.

***South Australian Sardine Fishery (Appendix 6.23, Goldsworthy)***

Community concerns about potential impacts on the ecosystem have been addressed by conducting field-based studies of predatory species and ecosystem modelling to inform the adaptive development of a precautionary assessment and management framework. This framework includes: (i) a stock assessment program based on fishery-independent surveys; (ii) a harvest strategy that includes decision rules for setting TACCs; (iii) a code of practice for mitigating operational interactions with protected species; and (iv) guidelines for managing the spatial distribution of catches.

The aims of the ecosystem-based study of the SASF were to: (i) identify the trophic interactions and functional groups most sensitive to variability in Sardine biomass; (ii) determine the sensitivity of land-breeding apex predators to changes in Sardine biomass and fishery catch, and assess their appropriateness as ecological performance indicators for the fishery; (iii) develop a food web model for the eastern Great Australian Bight and describe its temporal dynamics over the period since the SASF was established in 1991 using time-series data of fishing activity and environmental drivers; and (iv) examine ecosystem change through time using ecosystem indicators and assess their potential as ecological performance indicators of ecosystem health. Major baseline studies were undertaken on the ecology of key predators and prey. Dietary analysis of 37 pelagic fishes, squids, marine mammals and seabirds showed that most predators targeted multiple prey species (i.e. were generalists not specialists). Over 600 deployments of satellite tags were made on seven species. Most consumption by the five land-breeding predators consisted of fish (53%), squid (39%) and crustaceans (7%). Small pelagic fish accounted for 52% of fish consumed, but Sardines only accounted for ~4%. Crested Tern (*Thalasseus bergii*) was the only species where Sardine represented a significant component of prey (~23%) and consumption overlapped with the core part of the fishery. Ecosystem modelling suggested that despite the rapid growth of the SASF since 1991, there have been negligible impacts on other modelled trophic groups, and current levels of fishing effort are not negatively impacting the ecosystem function. The scale of the model is not appropriate to examine regional impacts, such as localised depletion.

***Marine mammal interactions with mid-water trawling in the Australian Small Pelagic Fishery (Appendix 6.24, Lyle)***

Marine mammal bycatch is an issue in trawl fisheries, especially mid-water trawlers. Exclusion devices are used to mitigate interactions. Interactions tend to be rare and/or sporadic and are difficult to observe and quantify. There is a need to understand the nature of the interactions, factors contributing to interactions and the consequence of interactions (lethal and sub-lethal effects). This issue came to light in the SPF in October 2004 when two consecutive mid-water shots resulted in 14 dolphin mortalities. The fishery was closed for a short period. Full observer coverage was enforced for six months, and exclusion devices modified. A code of conduct was implemented and the Cetacean Mitigation Working Group established. Conditions were placed on the Wildlife Trade Order. In 2004-2005, three additional incidents occurred in mid-water trawl nets involving 11 dolphin mortalities and at least 3 incidents involving seal mortalities. A pilot study using an underwater video camera system was instigated in June to September 2005. Nineteen trawl shots were monitored. High rates of seal interactions – entering through escape opening – were recorded. The soft mesh exclusion device was not adequate, being too flexible and not angled enough. Entries into the net were: via net mouth (93%); via the Seal Exclusion Device (SED) (6%); and unknown (1%). Outcomes were: exit via net mouth (24%); exit via SED opening (49%); uncertain (12%); and mortalities (13%). Mortality rates were estimated at 26% for the small SED and 5% for the large SED. Seal mortality rates in the SPF were high compared to other trawl fisheries: SPF: 0.23 seals per trawl (0.125 large opening and 0.360 small opening); blue grenadier fishery (demersal and mid-water trawl): 0.031-0.123 seals per trawl; South East Trawl (demersal): ~0.013 seals per trawl. There is a need to test alternative SED designs, especially top opening escape holes. No dolphin bycatch or interactions were recorded.

***Industry Code of Practice mitigates operational interactions of SASF with the short-beaked common dolphin (Appendix 6.25, Ward)***

The SASF was closed for two months in 2005 following an observer program that suggested ~1,728 dolphins were encircled and ~377 dolphins died across the fleet during a seven-month period in 2004-05. A Threatened, Endangered and Protected Species (TEPS) Code of Practice (CoP) was established in which industry committed to: (i) early detection through a dedicated search; (ii) avoidance through delayed setting when dolphins observed; (iii) swift action through rapid response to encirclement; and (iv) the application of several release procedures. A TEPS Working Group involving licence holders, skippers, fisheries managers and scientists was established. An induction program was developed for all new crew and skippers, and meetings were instigated to develop avoidance and release procedures.

An observer program in 2005-06 showed that rates of encirclement and mortality were reduced by 87% and 97%, respectively, following the implementation of the CoP. The CoP has been refined over time, and by 2013-14, observed rates of encirclement and mortality had stabilised at around 35 and 2 dolphins per hundred net sets, respectively. In 2011-12, industry initiated a real-time data collection program that has helped to reduce a discrepancy between interaction rates recorded by observers and those reported in logbooks. Results of this study emphasise the important role that establishing and maintaining an effective working relationship between industry and scientists can play in mitigating interactions of fisheries with protected species.

***Co-management initiatives in the South Australian Sardine Fishery (Appendix 6.26, Watson)***

There are currently two co-management initiatives in the SASF: (i) management of TEPS interactions through the TEPS Working Group and industry led “real time” monitoring; and (ii) optimisation of fish size through “real time” size data collection. Both initiatives require strong partnerships with researchers and managers to succeed. By 2011, the rates of interactions with dolphins had been significantly reduced.

However, a discrepancy remained between interaction rates recorded by observers and those reported in logbooks. Industry is now able to identify slippages in the interaction reporting rates in real time, supporting delivery of the objectives of the CoP. The real time program has re-shaped the effectiveness of the code and allowed industry to isolate where and when slippages and non-adherence may be occurring. The new system is effective, collaborative, transparent and an example of co-management. In 2015, with the assistance of government scientists, industry established a system for monitoring the size of fish taken in catches in "real-time". This system is now being used to optimise the size and quality of Sardines taken in the fishery. The SASF is committed to working with fisheries managers and scientists in the co-management of the SASF.

***Localised depletion (Appendix 6.27, Ward)***

*Australian Small Pelagic Fishery*

For the SPF, localised depletion is defined as: a persistent reduction in fish abundance in a limited area, caused by fishing activity, over spatial and temporal scales that causes a negative impact on predatory species and/or other fisheries. There is limited evidence of the occurrence of localised depletion or its impacts. It is a difficult question to address. If localised depletion is an issue, a better option may be to implement precautionary mitigation options. There are four main options for preventing or mitigating the effects of localised depletion: (i) conservative exploitation rates; (ii) increased spatial management through the establishment of 'zones' (management units) or setting spatially explicit TACs for the area surveyed; (iii) spatial/temporal closures (especially for central place foragers and other species with limited home ranges); and (iv) move on rules. These options are not mutually exclusive, and there may be benefits in establishing several or all of these options in some form.

*Californian Sardine Fishery*

To monitor for the occurrence of localised depletion, DEPM surveys are coupled with the CalCOFI surveys. CalCOFI provides comprehensive annual reports on the status of ecosystem.

*Bay of Biscay Anchovy Fishery*

Localised depletion is screened for by broadening DEPM surveys to obtain additional information from an ecosystem perspective, such as hydrographic characterisation, other species abundance estimates, stomach content of fish species, zooplankton distribution, and genetics of fish or microchemistry of otoliths.

*Atlantic Iberia Sardine and Horse Mackerel Fisheries*

In recent years, the data collection during the DEPM surveys has been enhanced and diversified, which not only promotes improvement in the method but also takes advantage of the comprehensive coverage of the pelagic environment and furthers the understanding of the ecosystem.

## Stakeholder Forum

***SPF industry perspective on key issues (Appendix 6.1, Gerry Geen)***

An SPF industry member outlined several problems confronting the SPF, including: limited offloading points and processing facilities; rapid rates of fish spoilage and the low value of products (bait and fishmeal). The industry member suggested that allowing a freezer-trawler to operate in the fishery would provide benefits including: (i) operating efficiency and profitability; (ii) high quality frozen product for human consumption; (iii) ability to move between fishing grounds; (iv) access to state-of-the art technologies; and (v) easier and more effective Government monitoring. Obstacles to the fishery that were identified included: (i) unrealistic information requirements by eNGOs (despite a strong body of research and industry commitment to fund ongoing DEPMs); (ii) marine mammal interactions (mitigated by top-opening SED, net bindings, auto-trawl, fishing grounds, dolphin and seal management plan, adaptation and refinement over time); and (iii) localised depletion – decreases in food supply for central place foragers and angler catch rates (mitigated by move on rules and spatial/temporal closures). The industry member identified the critical elements of a world class fishery using freezer-trawlers include: (i) precautionary harvest strategy; (ii) ongoing DEPM program; (iii) best practice mitigation technologies; and (iv) a package of spatial management arrangements to address the needs of central place foragers and user conflicts.

***SASF industry perspective on key issues (Appendix 6.2, Watson)***

A SASF industry representative stated that the SPF and SASF have been the subject of unprecedented public interest over the last few years. It was suggested that the fishing industry has been the subject of political conflict and been traded among politicians. The SASF representative suggested that people's lives and investments have been challenged and that marine parks and other pressures have demonised the Australian fishing industry. The SASF representative suggested that the key issue identified in the technical workshop was the need to develop tools to estimate stock levels. It was noted that harvest strategies need to be flexible enough to accommodate uncertainty and that the harvest strategy for the SASF provides this flexibility. The SASF industry representative stated that fisheries cannot develop without risk and that at some point issues need to be tested. It was noted that the SASF and Spencer Gulf Prawn Fishery (SGPF) went through a developmental process and are well managed, but that it would be challenging to develop these fisheries in the current political climate. It was stated that this was the challenge currently facing the SPF. The SASF industry representative emphasised the role of people in the fishing industry and the impact that the politicisation of fisheries has had on industry members and fishing communities.

***Small Pelagic Fishery Perspective (Appendix 6.3, Shanks)***

The *Fisheries Management Act 1991* (FM Act) provides the power for AFMA to regulate fishing by allowing for the establishment of management plans, which are legislative instruments that set out the management arrangements for a fishery. The objectives of the FM Act and management plans include: (i) implementing efficient and cost-effective fisheries management; (ii) ensuring exploitation of fisheries resources and related activities are conducted in a manner consistent with the principles of ecologically sustainable development (including the precautionary principle) and have particular regard to non-target species and the sustainability of the marine environment; (iii) maximising net economic returns to the Australian community from Australian fisheries; (iv) ensuring accountability to industry and the community in the management of fisheries resources; and (v) achieving government targets in relation to cost recovery in the fishery. The SPF is divided into two zones (East and West), and there are four target species: Jack Mackerel (*Trachurus declivis*, *T. murphyi*), Blue Mackerel (*Scomber australasicus*), Redbait (*Emmelichtys nitidus*) and Australian Sardine (*Sardinops sagax*). The SPF Harvest Strategy uses scientific outputs to determine exploitation rates/ levels for each stock in the two zones of the SPF based on three tier levels determined by information available on a stock. Environmental impact is mitigated through Ecological Risk Assessment (ERA) and Ecological Risk Management (ERM) reports, a Bycatch and Discarding Work Plan and export permit as an approved Wildlife Trade Operation (November 2012 to April 2015).

***South Australian Sardine Fishery (Appendix 6.4, Milic)***

The objectives of the *Fisheries Management Act 2007* are: (i) conserve and manage aquatic resources protect aquatic habitat and ecosystems; (ii) share access so the whole community gets the maximum possible benefit; (iii) foster recreational and commercial fishing activities; (iv) encourage stakeholders to participate in decision-making; (v) equitable allocation of resources between users; and (v) efficient and cost effective management. Fishery management plans have been developed for all major fisheries and must be consistent with the objectives of the Act. They also must set out a process to meet the objectives of the Act. A Minister must manage the fishery in accordance with the management plan. Management plans include: (i) fishery description (biological, economic and social); (ii) ecological risk assessment of effects of fishing; (iii) goals and strategies to address risks; (iv) harvest strategy; (v) outline co-management arrangements; (vi) allocate shares of the resources; (vii) specify stock assessment and research; and (viii) set the term of the management plan. Ecological risks of the effects of fishing are undertaken using National ESD Reporting Framework for Australian Fisheries. South Australia is currently developing a harvest strategy policy based on the '*National Guidelines to Develop Fishery Harvest Strategies*' (FRDC Project 2010/061). Policy for co-management of fisheries in South Australia describes responsibilities of both management and industry.

***Marine Stewardship Council: Low trophic level species (Appendix 6.5, Lefébure)***

The MSC works with partners to transform the world's seafood markets and promote sustainable fishing practices. The MSC standards for sustainable fishing and seafood traceability seek to increase the availability of certified sustainable seafood. Standards meet the world's toughest best practice guidelines. The issue of how to deal with ecosystem impacts of Low Trophic Level (LTL) fisheries has been recognised but until recently the guidelines have been unclear. The MSC set up an LTL Working Group in 2009 to review best practice guidelines. The review undertook wide stakeholder engagement, and commissioned a scientific study to use ecosystem models to explore trophic consequences of depleting LTL species. For key LTL species the default harvest strategy must either maintain 75% $B_0$ or have a target exploitation rate of $0.5F_{MSY}$ or 0.5M. These levels can be adjusted using the filters regarding: i) the proportion of the trophic connections in the ecosystem involve this stock (predator dependency); ii) the volume of energy passing between lower and higher trophic levels through this stock; and iii) the number of other species at this trophic level through which energy can be transmitted from lower to higher trophic levels (i.e. the proportion of the energy passing between lower and higher trophic levels passes through this stock). For non-key LTL species, the minimum default TRP is 40%$B_0$ and the minimum allowed LRP is 20% $B_0$ or half the TRP. For key LTL species at TRPs are more conservative. About 80 LTL stocks have been identified globally thus far; 19 are key LTLs based on the MSC criteria.

***Recreational fishing sector perspective (Appendix 6.6, Pike)***

In 2000, Recfish Australia launched a major public campaign related to large scale harvesting of Blue or Slimy Mackerel (*Scomber australasicus*) in the Jack Mackerel Fishery. Research undertaken on Blue Mackerel and other species resulted in a Management Plan for the Small Pelagic Fishery being established in 2009. The arrival in Australia in August 2012 of a large Dutch-owned and operated factory-freezer vessel was opposed by a large number of Australians. The recreational fishing sector and the conservation movement voiced concerns that research conducted in the SPF was inadequate to justify the operation of the factory-freezer vessel. Some academics and scientists declared that social license was 'lost'; however, social license was never gained. Politicians listened to voters and the federal government imposed a ban on super-trawlers. The recreational fisher considered that there has been an unprecedented lack of impartiality, independence and circumspection in the way many academics, scientists and fishery managers have defended inadequate data, imperfect scientific methodology and the super trawler venture itself. The management objectives for this fishery must include maintaining abundance levels to support the large populations of pelagic fishes and other species that depend on the resources of the SPF as food sources, particularly in areas important to the recreational fishing sector. It was suggested that research, science and data needed now to protect SPF stocks and their abundance in that ecosystem, include: 1) commitment to ongoing DEPM surveys across the SPF at Tier 3 of the current SPF Harvest Strategy; 2) recent, continuing, regular and geographically comprehensive DEPM surveys; 3) commitments that fishing-independent research and data will continue to precede development and management decisions in the fishery; 4) sound information on fish movements within SPF stocks to inform management on localised depletion and other issues; 5) management, including measurement or identification markers, to reduce the risk of localised depletion; 6) commitment to continuing and comprehensive observer coverage on all factory-freezer vessels; 7) greater transparency of fisheries management (AFMA's five boat rule is unacceptable); and 8) re-affirmation that recreational fishing and ecosystem considerations have equal weight with commercial considerations in relation to the SPF.

***One conservation perspective (Appendix 6.7, Graham)***

A conservation advocate stated that there had been a build-up of accumulated concern about how the SPF is managed. The main concern identified was the loss of non-industry stakeholder confidence. Another concern was the concept of economic value. The conservation advocate stated that there is substantial economic value in the SPF right now, through the recreational fishery, its tourism and recreational value, and most importantly, the value of species that depend on the small pelagic fishes for their existence. Commercial fishers and government institutions consider the value of commercial fisheries to be important, but it is not important to the broader community. The conservation advocate identified concerns about how society comprehends, trusts and responds to scientific information. It was suggested that there is a serious, systemic problem in fisheries in Australia, which was illustrated by the expert panel enquiry into freezer trawlers. Scientists, managers and commercial fishers all attended one session; conservationists and recreational fishers each had separate sessions. The conservation advocate suggested that this arrangement reflected the sense in the community that fisheries scientists, commercial fishers and fisheries managers work together. It was suggested that the approach gave the conservation and recreational sectors no option but to go to government and try to change the rules for the SPF. In the opinion of the conservationist, the reason for the current problem in the SPF is the failure of AFMA to maintain effective engagement with the conservation sector. It was asserted that AFMA does not give adequate consideration to non-industry stakeholders and that economic evaluations of the recreational sector and conservation values are needed so that the importance of these stakeholders to the Australian economy and society can be recognised. It was also stated that there is a need for a stronger commitment to effective engagement with recreational fishers and conservationists.

***WWF Australia: Conservation Perspectives on Small Pelagic Fisheries (Appendix 6.8, McCrea)***

The World Wildlife Fun (WWF) supports sustainable fishing that is (i) ecosystem-based managed, (ii) effectively regulated and enforced, and (iii) that does not damage sensitive/vulnerable habitats, ecosystems, biodiversity or populations of target and non-target species. LTL species can operate in an ecologically sustainable way, just like many other fisheries. LTL fisheries constitute one third of total world catch and like other species can be overfished. Overfishing can be exacerbated by responsiveness to oceanographic conditions and cycles and can cause potential ecosystem impacts by reducing food availability of higher trophic level predators. Forage fish are one of 15 Priority Commodities for the WWF Global Market Transformation Initiative. There has been a 28% decline in global biodiversity between 1970 and 2008. The Market Transformation Approach targets consumers, the supply chain and primary producers/extractors. It involves one-to-one corporate engagement with large companies on issues including wild caught seafood. The WWF position on LTL recommended aims are to: 1) prevent overfishing of target LTL populations; and 2) achieve healthy target populations in healthy marine ecosystems for all LTL-fisheries. These aims should be accomplished through: (i) precautionary and ecosystem based management approaches; (ii) Strategic Environmental Assessments, including cumulative effects; (iii) competent management authorities including governments, fisheries management bodies and RFMOs to develop roadmaps for the implementation; (iv) Rights Based Management; (v) manage according to FAO Code of Conduct for Responsible Fisheries; (vi) research and monitoring integrated into the harvest strategy; (vii) maintain the fished population at least at 75% of the spawning stock level in the absence of fishing; (viii) long-term research plans to assess the impacts of fishing on target and non-target populations and the effect on predators and other dependent species (fish, seabirds and marine mammals); and (ix) consideration of the need and value for temporal and spatial management.

***Overview of fisheries for small pelagic fishes***

Brief presentations were given on the assessment and management frameworks for the SASF and SPF (Ward), US Pacific Sardine Fishery (Lo), Chilean Sardine and Anchovy Fisheries (Cubillos), Bay of Biscay Anchovy Fishery (Ibaibarriaga), Atlantic Iberian Sardine Fishery (Angélico), European Mackerel Fishery (van Damme) and Greek Sardine Fishery (Ganias). Some of the similarities and differences in key elements of the approaches taken to stock assessment and management in six of these fisheries are summarised in Table 1.

**Table 1.** Key elements of the approaches taken to stock assessment and management in six pelagic fisheries.

| **Fishery** | **South Australian Sardine Fishery** | **Californian Sardine Fishery** | **Chilean Sardine Fishery** | **Chilean Anchovy Fishery** | **Bay of Biscay Anchovy Fishery** | **Atlantic Sardine Fishery** |
|---|---|---|---|---|---|---|
| Species | *Sardinops sagax* | *Sardinops sagax* | *Strangomera bentincki* | *Engraulis ringens* | *Engraulis encrasicolus* | *Sardina pichardus* |
| Primary management tool | TAC/ITQ | TAC (no ITQs) | TAC/ITQ | TAC/ITQ<br>Seasonal Closures | TAC | Size, Effort, Closures<br>Catch Quota Portugal |
| TAC/catch in 2014 | TAC 34,000 t | TAC 23,293 t | TAC 323,400 t | TAC ~630,000 t | TAC ~25,000 t | Catch ~45,000 t |
| Harvest strategy | Yes | Yes | Yes | Yes | Yes – applied, not formally accepted | Yes – used by Spain but not fully implemented |
| Key Performance Indicator | Spawning biomass<br>DEPM and Population model | Biomass<br>Population model | Fishing mortality<br>Population model | Fishing mortality<br>Population model | Spawning biomass<br>Population model | Spawning biomass<br>Population mode |
| Current Status (2015) | Sustainable | Closed | Fully exploited | Over-exploited | Sustainable (increasing) | Sustainable (declining) |
| Key management challenges | Capture of small immature fish | Shared stock<br>Environmentally driven variability in stock size | Mixed species in catches<br>Environmentally driven variability in stock size<br>Shared stocks | | Shared stock<br>(Spain and France) | Shared stock<br>(Portugal and Spain) |
| Application of DEPM | Biennial | Annual | Annual | Annual | Annual | Annual |
| Funding model | Cost recovery plus FRDC | Government | Permit fees | Permit fees | European Union | European Union |
| Stratification of egg survey | No (only positive and negative) | Post hoc – plus high/low using CUFES | Pre-survey stratification<br>High/low | Pre-survey stratification<br>High/low | Pre-survey strata Plus high/low using CUFES | Post hoc based on adult parameters (some years) |
| CUFES | Partial adaptive sampling | Adaptive sampling | No | No | Partial adaptive sampling | No |
| Statistical method used to estimate P0 | Linear model (multiple models – non-linear, GLM) | Non-linear regression | GLM negative binomial, log link | GLM negative binomial, log link) | GLM negative binomial, log link)<br>GAMs (spatial) | GLM negative binomial, log link)<br>Spatial data |
| Z estimated | Annually | Annually | Annually | Annually | Bayesian approach - Z priors from data series | Annually |
| Samples used to estimate Z | Eggs only | Eggs and yolk sac | Eggs only | Eggs only | Eggs and larvae | Eggs only |
| Adult sampling | Gill—net | Trawl | Purse seine | Purse seine | Trawl | Trawl, purse seine |
| Method used to estimate S | Average day-0, day-1, day-2 POFs | Average day-1 and day-2 POFs | day-1 POFs | day-1 POFs | day-0 and day-1<br>(bias correction) | POFs |
| Batch fecundity | Gravimetric method<br>Hydrated oocytes | Gravimetric method<br>Hydrated oocytes | Gravimetric method<br>Hydrated oocytes | Gravimetric method<br>Hydrated oocytes | Gravimetric<br>Hydrated oocytes | Shared stock |
| Other fishery-independent data | No | Aerial surveys<br>Acoustic surveys | Acoustic surveys | Acoustic surveys | Acoustic juvenile surveys | Acoustics |

# Discussion

## Synthesis of discussions at the technical workshop

### Funding model

In the SASF and SPF, stock assessment research is funded mainly through cost recovery from industry by the relevant fisheries management agency (PIRSA Fisheries and Aquaculture, AFMA). In the USA, stock assessment is funded entirely by government. In Europe, stock assessment and related research is mainly funded by the European Union. In Chile, this work is funded from industry permit fees.

It was recognised that cost-recovery provides a reliable source of ongoing funding and helps to ensure that research is targeted on management questions. The main weakness is that cost-recovery may not provide adequate funds to support assessment of small or depleted fisheries.

Reliance on government funding for stock assessment and related research can also be problematic, especially when the economic situation is poor. It was widely acknowledged that FRDC is good model for supporting the research required for the development and ongoing refinement of fisheries.

### Stock assessment

In Europe, all countries with access/quota participate in the stock assessment. Technical groups gather samples, perform surveys, etc. Assessment groups analyse data, conduct statistical analyses and run models. This division leads to a number of issues regarding communication, etc. A more integrated approach to stock assessment is taken in most other jurisdictions, including Australia.

### Use of DEPM estimates

Australia is the only jurisdiction considered during the workshop where estimates of spawning biomass from the DEPM are used directly to set TACs. Low levels of fishing currently impede use of population models in the SPF. In all other fisheries discussed, DEPM outputs are used as inputs to population models that generate outputs that are used to set TACs. The use of population models is particularly important in situations where egg surveys do not cover the entire spawning area (e.g. USA where the peak spawning season varies along the coast). In these situations, population models can also incorporate data from alternative sources (e.g. acoustics surveys for juveniles and adults, aerial surveys). There is a need to weight data from different sources (e.g. acoustic versus DEPM surveys); it was noted that weightings vary among jurisdictions and are subjective.

Acoustic surveys are undertaken in USA, Europe and Chile. Acoustic surveys are conducted concurrently with the DEPM survey in Bay of Biscay, but this has logistical implications (e.g. plankton surveys because of timing and location of acoustic surveys). Species identification can be problematic in acoustic surveys. Acoustics consistently estimate lower biomasses than DEPM in Iberian Horse Mackerel, but provide higher estimate for Pacific Sardine off USA.

It was noted that an industry-funded project is currently underway to evaluate the benefits of using a population model and/or DEPM estimates of spawning biomass to set TACs in the SASF.

## Survey design

In the SASF, the DEPM survey area is predetermined and a CUFES is used to ensure that areas where spawning occurs adjacent to the survey area (i.e. on the end of transects) are sampled. In Chile, areas where spawning is considered unlikely to occur (based on previous surveys) are not surveyed due to resource limitations. The use of the CUFES in an adaptive sampling context has been important in the USA where egg surveys are conducted as part of a broader ecosystem program (CalCoFI) and a large amount of time is spent at each sampling site (e.g. several hours at each site, transects 40 nm apart). In the USA, a transect ends once egg densities from CUFES drop below a specified threshold.

A pre-determined sampling design is beneficial when surveys are dedicated to application of the DEPM and the time spent at each site is low enough to allow high intensity sampling (e.g. SASF, 5 minutes on each station; transects 15 nm apart; stations 4 nm apart). Spatial autocorrelation is a potential issue if transects are too close together; geo-statistic models are an option in this case, with transect-level random effects. Bootstrapping can be used to address possible correlation between stations.

Future surveys off the east coast of Australia need to cover the entire spawning area and be conducted during the peak spawning season. Spawning dynamics along the east coast are poorly understood but have significant implications for DEPM surveys (i.e. what proportion of the adult population is outside the spawning area and not spawning during the survey?). Additional sampling and modelling could be undertaken to determine the proportion of (non-spawning) adult fish outside the main spawning area during the peak spawning season.

## Egg production

Analyses done in the Bay of Biscay show the benefit of using data from all years combined to estimate egg mortality rates. Experience in the USA and Bay of Biscay also show the benefits of using densities of yolk-sac larvae to estimate egg production; noting that this requires estimation of the age of yolk-sac larvae). Attempts in the USA to use CUFES data to estimate mortality and egg production have been unsuccessful.

It was generally agreed that statistical models used to estimate mortality and egg production need to be chosen to fit the distribution of individual datasets (i.e. for species and location being considered).

FRDC Project 2014/026, "*Improving the precision of estimates of egg production and spawning biomass obtained using the Daily Egg Production Method*") is aiming to develop guidelines for estimating $P_0$ for different species.

## Adult sampling and spawning fraction

Spatial and temporal synchronisation of egg and adult sampling is important in the application of the DEPM. Commercial vessels may not provide representative samples of the adult population. For example, in the USA and South Australia, most fishing occurs inshore and targets relatively young fish. However, commercial vessels are used successfully to collect adult samples in Chile. The benefits of collecting fishery-independent adult samples, including the ability to ensure synchronization with the plankton survey, were widely acknowledged.

The importance of estimating spawning fraction annually was widely recognised. Estimates of spawning fraction are most critical for species that spawn infrequently (i.e. low spawning fraction), such as Sardine and Anchovy. New methods for estimating spawning fraction have been developed in the Bay of Biscay based on experimental examination of effects of temperature on POF degradation.

Aggregation biases need to be considered when estimating spawning fraction. Sampling at specific time intervals is a good option for addressing this issue. Restricting sampling to large non-spawning schools should also be considered. Choosing appropriate POF stages for calculating spawning fraction is important as some POF stages can be over-represented in trawls (e.g. day-0 POFs in USA).

The gill-net used in the SASF does not consistently produce samples that are dominated by one particular POF stage, suggesting samples may be unbiased with respect to POF stage. However, there is a need to clearly define day-0 fish; hydrated females should be treated separately from those with early stage POFs as they are likely to spawn on different days. The potential effects of different rates of POF degradation among and within species need to be considered.

The scientific panel recognised that a project to compare the abundance of different POF stages and estimates of spawning fraction in samples from gillnet, purse-seine and trawl would be beneficial. It was recommended that methods used to estimate spawning fraction in the SASF should be reviewed.

## Batch fecundity

Estimating batch fecundity using the standard gravimetric or volumetric methods can be difficult because hydrated females are rare in the population, especially for species with low spawning fractions. The relationship between fish size and batch fecundity is relatively stable among years. It was agreed that estimates of this relationship can be based on data from multiple years.

Alternative methods for estimating batch fecundity need to be considered if hydrated females cannot be collected in sufficient numbers to provide robust estimates of this parameter. Options include counts of tertiary stage oocytes and oocytes with migrating nuclei based on histological slides. These approaches are also limited to oocytes that are relatively rare. An automated approach to counting hydrated and non-hydrated oocytes may: increase the number of specimens for batch fecundity measurements; increase accuracy; save time (five to six times faster compared to the classical method); and provide archives of digital microphotographs for future analysis

## Harvest strategies

Similar harvest strategies are used to set TACs in most jurisdictions. Biomass indicators with target and limit reference points are widely used.

The harvest strategy for the SASF was considered to be similar to those used in other comparable fisheries and consistent with international benchmarks for low trophic level species (e.g. MSC; Lenfest Task Force). The establishment of size-based performance indicators to address the potential for reductions in the abundance of adult Sardines on key fishing grounds was recognised as being a precautionary and innovative approach to managing potential ecosystem impacts.

In Chile and the Bay of Biscay, TACs are adjusted during the season based on results of juvenile acoustic surveys. Consideration could be given to establishing recruitment indices in the SASF to adjust TACs within a season. However, the potential costs and benefits of this approach would need to be evaluated.

The use of exploitation rates rather than biomass levels to determine TACs is appropriate in developmental fisheries such as the SPF, where an understanding of biomass levels is relatively poor. Target and limit reference points in the SPF have been reviewed (see Smith et al. 2015) and used to adjust exploitation rates for some species.

## Ecosystem based management

In the USA, DEPM surveys are conducted within the context of a broader, ongoing ecosystem study of the California Current System (i.e. CalCOFI, http://www.calcofi.org/index.php). This approach has implications for how the DEPM is applied (i.e. reliance on CUFES to inform adaptive sampling), but provides a sound basis for monitoring changes in the pelagic ecosystem. In Europe, ecosystem data are increasingly being collected during egg surveys. However, currently there is limited analysis of these ecological data. In CCAMLR, a precautionary approach is taken to managing the ecosystem effects of Krill fishing on forage species. This includes a precautionary cap on the Krill fishery. The use of reference areas to test the effects of fishing and management approaches is currently being considered.

The dedicated study of the role of Sardine in the pelagic ecosystem off South Australia and the use of an ecosystem model to assess potential impacts of fishing (Goldsworthy et al. 2011) was acknowledged as being beyond what has been done in most jurisdictions (with the exception of CalCOFI). The benefits of extending this program beyond the snapshot undertaken in the FRDC study to become an ongoing program similar to CalCOFI were recognised. However, the high costs of establishing and maintaining such a program were also noted.

The potential for using data from the ichthyoplankton surveys to monitor the pelagic ecosystem was emphasised strongly. It was acknowledged that samples collected from DEPM surveys should be used to provide information about ecosystem structure. Projects are currently underway to use historical plankton samples from South Australia to examine: 1) the effects of upwelling strength on the trophic structure of the pelagic ecosystem; and 2) environmental factors affecting spatial and temporal patterns of distribution and abundance in the ichthyoplankton assemblage.

### Localised depletion

Scientific participants recognised the technical difficulties associated with measuring localised depletion. The precautionary approaches to addressing the potential for localised depletion of the target species implemented by CCMLAR and in the SASF were recognised as pragmatic and adaptive options for addressing this issue. It was generally agreed that consideration should be given to establishing guidelines to reduce the risk of localised depletion occurring in the SPF.

## Synthesis of discussions at the stakeholder forum

The stakeholder forum was well attended by industry stakeholders but few conservation and recreational fishing stakeholders were present. It was widely acknowledged that the assessment and management framework for the SASF compared well to fisheries for small pelagic fishes around the world. Industry representatives from both the SPF and SASF expressed concerns about the increasing influence of environmental groups on fisheries management. One speaker from the conservation sector expressed concern about the limited influence of non-industry stakeholders in fisheries management. A speaker from the recreational fishing sector expressed concern about the lack of scientific information available for the SPF and the need for recreational fishing and ecosystem considerations to be given equal weight to commercial considerations.

International scientists at the forum considered Australia's consultative processes for small pelagic fisheries to be relatively well advanced compared to most other fisheries considered.

# Conclusions and Implications

*Technical workshop*

Presentations and discussions at the workshop demonstrated that the assessment and management frameworks for the SASF compare favourably to other small pelagic fisheries worldwide. It was noted that a suite of research projects is currently underway to further improve these approaches and support the adaptive management of the SASF and SPF. Basing the development of the SPF on approaches used in the successful development of the SASF was also recognised as being appropriate.

The scientific panel considered that the application of the DEPM in Australia compared favourably to other fisheries and noted that ongoing refinements of the DEPM are underway in several countries. Several options for improving statistical methods used to estimate egg production in Australia and elsewhere were identified. The importance of FRDC Project 2014/026 that is developing guidelines for estimating egg production was widely acknowledged. It was recognised that South Australia is the only jurisdiction in which adult samples are collected using gill-nets; the benefits of conducting a research project to compare estimates of adult parameters obtained using gill-nets, purse-seines and trawls was identified. It was also suggested that the approaches used to estimate spawning fraction in the SASF should be reviewed, noting that a similar review was conducted in the Bay of Biscay Anchovy Fishery.

The harvest strategy for the SASF was considered to be both similar to those used in comparable fisheries and consistent with international benchmarks for low trophic level species (e.g. MSC; Lenfest Task Force). However, the SASF is the only established fishery considered at the workshop where estimates of spawning biomass are used directly to set TACs. It was recognised that a project to explicitly examine the benefits and limitations of using a population model and/or DEPM estimates of spawning biomass to set TACs in the SASF was warranted. Structuring the SPF harvest strategy around conservative exploitation rates was considered to be appropriate for a developing fishery where biomass levels are poorly understood.

The establishment of size-based performance indicators to address reductions in the abundance of adult Sardines on key fishing grounds was recognised as being a precautionary and innovative approach to managing potential ecosystem impacts. It was generally agreed that consideration should be given to establishing harvest guidelines to reduce the risk of localised depletion in the SPF.

International scientists considered that the SASF compares well to most other fisheries worldwide in the assessment and management of ecosystem effects, including consideration of trophic impacts and monitoring and mitigation of interactions with protected species. Few other fisheries have conducted comprehensive field-based assessments of the role of the target species in the ecosystem and developed system-specific ecosystem models to assess potential ecosystem impacts. The benefits of establishing an ecosystem program comparable to the ongoing study of the role of the Pacific Sardine in the California Current System (http://www.calcofi.org/index.php) were widely acknowledged. It was recommended that ecosystem studies similar to those done in the SASF should be conducted for the SPF if/when it is developed into a substantial fishery.

*Stakeholder forum*

The stakeholder forum was well attended by industry stakeholders but relatively few conservation and recreational fishing stakeholders were present. It was widely acknowledged by those present that the assessment and management framework for SASF compared well to fisheries for small pelagic species around the world. Most concerns expressed by stakeholders related to issues associated with the introduction of a large freezer-trawler into the SPF. Industry stakeholders expressed concerns that political intervention into fisheries management over this issue set a dangerous precedent and that conservation and recreational fishing stakeholders had “unrealistic” expectations regarding the level of scientific information that should be acquired prior to the development of the fishery. Some conservation and recreational fishing stakeholders expressed concerns that their views were not given adequate consideration by fisheries management agencies (and scientists) and that more research was needed before large-scale harvesting should commence in the SPF. The disparate views of stakeholder groups were not resolved at the forum. However, it was widely agreed that effective communication among stakeholders and a genuine a co-management approach should be re-established to support future management of the SPF.

# Recommendations and further development

**Recommendations and further development**

The workshop identified several areas of research that should be undertaken to improve the assessment and management frameworks for Australia's small pelagic fisheries, including:

1) comparing estimates of adult parameters obtained using gill-nets, purse-seines and trawl-nets;
2) reviewing approaches taken to estimating spawning fraction in the SASF;
3) examining the benefits and limitations of using a population model and/or DEPM estimates of spawning biomass to sets TACs for Sardine and other species.

It was generally agreed that consideration should be given to establishing precautionary guidelines to reduce the risk of localised depletion in the SPF. It was widely agreed that effective communication among stakeholders and a genuine a co-management approach should be re-established to support future management of the SPF.

# Extension and Adoption

Scientists, fisheries managers, industry and other stakeholders in the SASF and SPF attended this workshop and forum. Copies of the final report will be disseminated to all relevant parties. Presentations on the findings of the workshop have been, and will continue be, presented directly to fisheries managers, industry and other stakeholders involved in the SASF and SPF.

## Project coverage

Media releases on the workshop were made by PIRSA Fisheries and Aquaculture, SARDI and Senator Richard Colbeck, Parliamentary Secretary to the Minister for Agriculture.

# Project materials developed

Abstracts and presentations are provided as an appendix to this report.

# Appendices

## 1. References

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## 2. List of researchers and project staff

*Convener*

Associate Professor Tim Ward

*Chair*

Professor Colin Buxton

*Speakers*

*International scientists*

Dr Nancy C.H. Lo, NOAA Affiliate, South West Fisheries Science Center, USA

Professor Luis A. Cubillos, Departamento de Oceanografía, University of Concepción, Chile

Dr Leire Ibaibarriaga, Marine Research Division, AZTI-Tecnalia, Spain

Dr Maria Manuel Angélico, Portuguese Institute for the Ocean and Atmosphere, Portugal

Dr Cindy J.G. van Damme, Institute for Marine Resources and Ecosystem Studies, Netherlands

Dr Kostas Ganias, Laboratory of Ichthyology, Biology, Aristotle University of Thessaloniki, Greece

*Australian Scientists*

Dr Jonathan Carroll, South Australian Research and Development Institute, Australia

Dr John Keane, Institute for Marine and Antarctic Studies, Australia

Dr Richard Saunders, Queensland Department of Primary Industries

Dr Mike Steer, South Australian Research and Development Institute, Australia

Dr Tony Smith, CSIRO, Australia

Dr Jess Melbourne-Thomas, Australian Antarctic Division

A/Prof Simon Goldsworthy, South Australian Research and Development Institute, Australia

Dr Jeremy Lyle, Institute for Marine and Antarctic Studies, Australia

*Fisheries Managers*

Mr Sean Sloan, Primary Industries and Regions South Australia

Mr Steve Shanks, Australian Fisheries Management Authority

Mr Brad Milic, Primary Industries and Regions South Australia

*Stakeholders*

Mr Gerry Geen, Seafish Australia Pty Ltd

Mr Paul Watson, South Australian Sardine Industry

Mr Robert Lefébure, Marine Stewardship Council

Mr Graham Pike, recreational fishing sector

Mr Alistair Graham, conservation

Ms Joanne McCrea, World Wildlife Fund

# 3. International speakers

***Dr Nancy Lo***

Nancy C. H. Lo received her PhD in statistics from Oregon State University in 1972. She worked for the California Department of Fish and Game (CDFG), Menlo Park, California from 1973–76 before she joined the Marine Mammal Division, Southwest Fisheries Science Center (SWFSC), National Marine Fisheries Service in La Jolla, CA. She transferred to the Coastal Fishery Division (presently the Fisheries Resources Division) in 1981, till her retirement at the end of 2011. Much of her work was focused on analysis of plankton survey data and quantification of new survey methodologies so that fish egg and larval data could be more effectively used to monitor the relative abundance of commercial species, and interpret their life history, e.g. sampling schemes of fishery-independent sea and aerial surveys, fishery-dependent survey; estimation of biological parameters; and spawning biomass estimates, in particular using the daily egg production method (DEPM) for coastal pelagic species (CPS), which has been an input time series to the stock assessments of northern Anchovy and Pacific Sardine in the US. To improve survey efficiency, Nancy developed an efficient adaptive allocation survey design for Pacific Sardine DEPM-ichthyoplankton-trawl surveys, using the Continuous Underway Fish Egg Sampler (CUFES) in 1977. She developed the stage-specific matrix model to estimate vital rates of Anchovy and Sardines: mortality, growth rates of each life stage, fecundity rates, and to evaluate the sensitivities of changes in vital rates on the population growth of Anchovy and Sardines. Nancy explored methods other than plankton-based surveys for monitoring the relative abundance of fishes, like the aerial survey of SPC off California using the spotter pilot logbook data and the exploration of the feasibility of using an aerial survey using LIDAR (light detecting and ranging) by developing a model to evaluate such a survey approach. Nancy emphasizes the importance of using proper statistical applications to fishery problems and the interactions with scientist around the world.

***Professor Luis Cubillos***

Luis Cubillos is a Professor at the University of Conception in Chile. He has applied the Daily Egg Production Method Anchovy (*Engraulis ringens*) and common Sardine (*Strangomera bentincki*) off central Chile for over 11 years. He has published over one hundred scientific papers which have been cited over 1308 times.

***Dr Leire Ibaibarriaga***

Leire Ibaibarriaga (PhD) is a senior researcher in the Marine Research Division at AZTI Tecnalia. Her main interests are fish population dynamics models (especially Bayesian state space models), management strategy evaluation, daily egg production method and statistical modelling of biological processes. She has participated to several EU projects related to the assessment and management advice of small pelagic stocks (FISBOAT, SARDONE, UNCOVER, MEECE, EURO-BASIN). She is a member of several ICES (International Council for the Exploration of Sea) working groups, including the working group on southern Horse Mackerel, Anchovy and Sardine (WGHANSA). She has been an invited expert in various STECF (Scientific, Technical and Economic Committee for Fisheries) meetings regarding the assessment and development of a long term management plan term proposal for the Bay of Biscay Anchovy. She has contributed to 19 scientific papers in peer review journals.

***Dr Maria Angelico***

Maria Angelico has a PhD in Biological Oceanography involved in studying the distribution and dynamics of early life stages of fish and invertebrates and zooplankton ecology. I´m currently responsible for the Portuguese DEPM surveys (undertaken within the EU-DCF programme) directed at the estimation of the spawning stock biomass for Sardine and Horse-Mackerel in the Atlantic Iberian waters. Also coordinator for environmental surveying (plankton, hydrography, chemistry) during the acoustics surveys for small pelagic fishes. At present I´m co-chair of the ICES Working Group on Acoustics and Egg Surveys for Sardine and Anchovy in ICES areas VII, VIII and IX (WGACEGG) and the Working Group on Atlantic Larvae and Egg Surveys (WGALES).

***Dr Cindy van Damme***

Cindy has been working at IMARES since 2002, where she is in charge of ichthyoplankton surveys and reproductive biology studies. Member of ICES working groups; WGALES (Working group for Atlantic fish larvae and egg surveys; current co-chair), WGEGGS2 (Working group for North Sea plaice and cod egg surveys), WGMEGS (Working group for Mackerel and Horse Mackerel egg surveys; current co-chair), WKFATHOM (Workshop on egg staging, fecundity and atresia in Horse Mackerel and Mackerel; current chair) and WKMSMAC2 (Workshop on sexual maturity staging of Mackerel and Horse Mackerel; current co-chair). Within WGMEGS she is co-coordinator for the adult fecundity and atresia sampling.

She is in charge of the Dutch participation in: the North plaice and cod egg survey using the AEPM method for estimating plaice SSB, the triennial Atlantic and North Sea Mackerel and Horse Mackerel egg survey using the AEPM for estimating Mackerel SSB and producing an egg production of Horse Mackerel, yearly North Sea herring larvae surveys estimating SSB from newly hatched larvae and producing a recruitment index. A national project in 2010-2011 was a year-round monthly ichthyoplankton survey in the southern North Sea. She finished her PhD on reproductive biology of different fish species in the North East Atlantic in 2013. Currently a project is run to compare the use of AEPM and DEPM for the Mackerel SSB estimate from the 2013 Atlantic Mackerel egg survey.

***Dr Costas Ganias***

Dr. Konstantinos Ganias is a biologist (1997, School of Biology, Aristotle University of Thessaloniki; AUTH) and received his Ph.D. (2003) from the Department of Ichthyology and Aquatic Environment, University of Thessaly. He did part of his post-doctoral research at the Institute IPMA (Lisbon) and received training in several universities and research institutes (School of Biological Sciences, Scotland; AZTI, Spain; IMR, Norway; HCMR, Greece). Since 2013 he serves as a Assistant Professor in 'Biological Oceanography' at the School of Biology, AUTH (previously served as Lecturer at the same position since 2006). He supervised/s a number of undergraduate and post-graduate theses. He has been invited keynote speaker in one international conference and invited speaker in several workshops and research institutes. His research mostly investigates fish reproductive biology, application of egg production methods for the estimation of fish spawning biomass, and environmental effects on the reproductive potential of fish stocks

# 4. Agenda: Technical workshop and stakeholder forum on small pelagic fisheries

**Dates**: 14-18 July 2014

**Location**: South Australian Aquatic Sciences Centre, Adelaide, South Australia

**Convener**: Tim Ward, South Australian Research and Development Institute, Australia

**Chair**: Colin Buxton, Institute for Marine and Antarctic Studies, Australia

***Day 1: The American experience: lessons from the first and the biggest***

**DATE:** 14 July

Welcome by convener, rationale for workshop and forum (Tim Ward)

Loss of social license to fish: Commonwealth Small Pelagic Fishery (Colin Buxton)

Australia's fisheries for small pelagic species; focus on SA Sardine Fishery (Tim Ward)

Californian Sardine 1986-2013 (Nancy Lo)

Sardine and Anchovy central Chile (Luis Cubillos)

Introduction to the European collaborative platforms (WGACEGG, WGALES, etc) and overview of European fisheries (Cindy van Damme and Maria Manuel Angélico)

***Day 2: The European experience: benefits of collaboration***

**DATE:** 15 July

Bay of Biscay Anchovy 1987-2013 (Leire Ibaibarriaga)

Atlantic Sardine and Horse Mackerel (Maria Manuel Angélico)

Mackerel spawning stock biomass: comparing annual and daily egg production methods (Cindy van Damme)

12.45 pm Overview of Statistical Approaches; South Australian Sardine Fishery (Jonathan Carroll)

Discussion (Colin Buxton)

- survey design
- statistical approaches to estimating daily egg production
- is there a growing consensus
- opportunities for a joint paper

***Day 3: Looking to the future: opportunities for improvement***

**DATE:** 16 July

The adult survey of DEPM: still room to improve – (Kostas Ganias)

Development and application of a rapid molecular identification technique for fish eggs (Richard Saunders)

Application of DEPM to Snapper: past present and future – (Mike Steer and Gary Jackson)

Genetic validations for SPF species and overview of recent work– (John Keane)

Australia's developing fisheries: SPF, NT and Tasmania (Tim Ward)

DEPM wrap-up: planning the future (Colin Buxton)

- lessons learned about application of the DEPM – is there a consensus
- what are the priorities for developing fisheries – starters guide
- how do we collaborate better
- other opportunities for publications?

Harvest strategies; using biomass estimates to set quotas (Sean Sloan)

SASF Harvest Strategy (Tim Ward)

US Harvest Control Rules (Nancy Lo)

European Harvest Control Rules (Leire Ibaibarriaga, Maria Manuel Angélico, Cindy van Damme)

Chilean Harvest Control Rules (Cubillos)

Discussion: What would an ideal harvest strategy look like for a small pelagic species?

***Day 4: Ecological issues: trophic impacts, interactions with protected species and localised depletion***

**DATE:** 17 July

Managing for ecosystem effects of fisheries for small pelagic species (Tony Smith, CSIRO)

Practical approaches to mitigating ecosystem impacts: CCMALR Experience (Dr Jess Melbourne-Thomas)

Ecosystem research: case study South Australian Sardine Fishery (Simon Goldsworthy)

Interactions with protected species: seals in mid-water trawls (Jeremy Lyle)

Interactions with protected species: dolphins in purse seine nets (Tim Ward)

Industry Initiatives: progress towards co-management in the South Australian Sardine Fishery – (Paul Watson)

Localised depletion: definition, examples and mitigation options (Tim Ward)

Discussion of localised depletion (Facilitated by Colin Buxton)

What is likelihood of localised depletion of small pelagic fishes?

***Day 5: Stakeholder forum: benchmarking Australia's fisheries science for small pelagic species against World's best practice***

**DATE:** 18 July

Welcome by convener (Tim Ward)

Opening by PIRSA Chief Executive (Scott Ashby)

Industry Perspective (Gerry Geen, Seafish Tasmania)

Industry Perspective (Paul Watson, SA Sardine Industry)

AFMA Perspective (Steve Shanks, AFMA)

PIRSA Perspective (Brad Milic, PIRSA)

Marine Stewardship Council Guidelines (Rob Lefebure, MSC)

Recreational Sector Perspectives (Graham Pike, Recreational fishing sector)

A Conservation Perspective (Alistair Graham, Conservation)

WWF Perspectives (Jo-anne McCrea, WWF)

The Australian situation: SASF and Commonwealth Small Pelagic Fishery (Tim Ward)

North American Sardine (Nancy Lo)

South American Sardine and Anchovy (Luis Cubillos)

Spanish Anchovy (Leire Ibaibarriaga)

Atlantic Sardine (Maria Manuel Angélico)

Atlantic Horse Mackerel (Cindy van Damme)

Mediterranean Sardine (Kostas Ganias)

***Panel discussion - questions from stakeholders (facilitated by Colin Buxton)***

(Lo, Cubillos, Ibaibarriaga, Angelico, van Damme, Ganias, Melbourne-Thomas)

**How do Australian fisheries stack up?**

**How can we improve?**

# 5. Abstracts

***Day 1: The American experience: lessons from the first and the biggest***

LOSS OF THE SOCIAL LICENCE TO FISH: COMMONWEALTH SMALL PELAGIC FISHERY

Professor Colin D. Buxton and Dr Jeremy Lyle

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The Commonwealth Small Pelagic Fishery (SPF) encompasses Commonwealth waters (3-200 nm from the Australian coastline) from southern-eastern Queensland around southern Australia to Western Australia and is divided into two management sub-areas. The target species include blue Mackerel (*Scomber australasicus*), three species of jack Mackerel (*Trachurus declivis, T. symmetricus, T. murphyi*), redbait (*Emmelichthys nitidus*) and Australian Sardine (*Sardinops sagax*).

Although sporadic fishing activity has been undertaken since the mid-1980s, the SPF is still very much in a developmental phase. Significant fishing for jack Mackerel occurred in the 1980s and 1990s, with most fishing activity centered off Tasmania because of limitations on the vessel range and the port facilities. It has involved both purse seine (targeting jack Mackerel) and mid-water trawl activity (targeting redbait and jack Mackerel) with over 100,000 t taken in three years during the 1980s and catches throughout the 1990s averaging over 10,000 t per annum.

The fishery substantially reduced in scale and catch during the 2000s and 2010s because it was very marginal economically. This strengthened the resolve to introduce factory trawling into the fishery, something that was first mooted in 2004. It was resisted at the time because it was felt that there was not an appropriate management framework, nor sufficient understanding of the stocks. What followed was an intensive period of research and policy development which led to the introduction of a Management Plan, Ecological Risk Assessment, Harvest Strategy, accreditation under the Environmental Protection and Biodiversity Conservation Act, export permission and ITQ Statutory Fishing Rights. In effect the SPF management regime was completed in 2012.

Following a period of consultation with the Commonwealth Government and AFMA in 2011, a local fishing company, Seafish Tasmania, announced plans to introduce the *Margiris*, a large Dutch-owned factory trawler, into the SPF. At the same time Seafish provided written briefings to the government (Labour and Liberal), and advised peak industry bodies and ENGOs of their plans.

The announcement that the *Margiris* was to leave Europe bound for Australia precipitated a Greenpeace led petition and protest against its potential to overfish Australian waters. This action was joined by several other Australian ENGOs and the recreational fishing fraternity, who mounted an intense social media campaign against the so-called supertrawler.

Much of the social media and other commentary was fuelled by misinformation and a disregard of the science underpinning the fishery. However, the campaign forced the Commonwealth Government to change legislation and to back down from their initial support of factory trawling in the SPF, implementing a two year

moratorium on vessels over 130m pending the outcome of a review into the fishery. This effectively stopped the *Margiris*.

This presentation examines the loss of social licence to fish and the lessons learned from the campaign against the introduction of factory trawling into the SPF. It concludes that although the science behind the SPF was relatively robust, science communication was ineffective in the public debate. Allowing political pressure to override policy is seen as a backward step and, while it can be a positive that interest groups are becoming more engaged, if they are misinformed or they misinform the general public, their influence may be negative on established governance systems, potentially leading to undesirable outcomes for society as a whole.

AUSTRALIAN FISHERIES FOR SMALL PELAGIC FISHES,

Tim Ward,
South Australian Research and Development Institute (SARDI), Aquatic Sciences, PO Box 120, Henley Beach, SA 5022, AUSTRALIA
tim.ward@sa.gov.au

This paper highlights issues that need to be addressed if fisheries for forage species are to demonstrate their ecological sustainability and maintain a social license to fish (i.e. community "approval"). Two Australian fisheries with similar assessment and management frameworks but different public perceptions are used to highlight the complexity of this challenge.

The South Australian Sardine Fishery (SASF) was established in 1991 to provide fodder for the tuna farming industry and is Australia's largest volume fishery. This rapid development occurred despite significant challenges; for example, mass mortality events in 1995 and 1998 each killed >60% of the adult population. Serious community concerns about potential impacts on the ecosystem have been addressed by conducting field-based studies of predatory species and ecosystem modelling to inform the adaptive development of a precautionary assessment and management framework. This framework includes: a stock assessment program based on fishery-independent surveys; a Harvest Strategy that includes decision rules for setting the quota; a Code of Practice for mitigating operational interactions with protected species; and guidelines for managing the spatial distribution of catches.

The Commonwealth Small Pelagic Fishery (SPF) was established in 2002. The Management Plan for the SPF draws heavily on the approach taken in the SASF and was developed with the involvement and support of stakeholders. In 2012, an attempt to introduce a large factory trawler into the fishery led to a public outcry that resulted in legislative changes that prevented the vessel operating in the SPF and severely damaged the fishery's social license to operate. This outcry was led by recreational fishing and conservation groups that had previously supported the Management Plan.

The Australian community's contrasting perceptions of the SASF and SPF highlight the complex challenges that must be addressed to establish and retain a social license to fish in modern Australia and elsewhere. In this talk I describe how the SASF's social license to operate was established, what happened in the SPF and what is now being done to address actual and perceived weaknesses in the SPF's assessment and management framework.

DAILY EGG PRODUCTION METHOD APPLIED TO PACIFIC SARDINE (Sardinops sagax) OFF CALIFORNIA FROM 1986-2013

Nancy C. H. Lo, NOAA Affiliate, Southwest Fisheries Science Center, 8901 La Jolla Shores Dr., La Jolla CA
Nancy.Lo@NOAA.gov

Pacific Sardine (*Sardinops sagax*) has a long history of fisheries beginning in the early 1930s. The population started to decline in the mid-1940s and a moratorium was enforced in the mid-1960s. No Sardine occurred in the commercial catch off California until the mid-1980s. Special cruises were conducted by California Department of Fish and Game (CDFG) and National Marine Fisheries Service (NMFS) to estimate the spawning biomass of Pacific Sardine in late 1980s using the daily egg production method (DEPM). Since 1994, DEPM survey coupled with California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey were conducted in most years to estimate the spawning biomass of Pacific Sardine. The major driving force of the spawning biomass is the daily egg production ($P_0$). Spawning biomass is the longest fishery-independent time series of biomass index used in the stock assessment of Pacific Sardine. Two additional fishery-independent biomass time series are from aerial survey off NW beginning in 2009 and acoustic survey beginning in 2011.
This talk reports design-based DEPM applied to Pacific Sardine off California: 1) DEPM survey design: adaptive allocation sampling since 1997, 2) estimation of daily egg production ($P_0$), by two statistical methods: nonlinear regression, and GLM and 3) Time series of egg production with sea surface temperatures and spawning biomass from 1986-present.

IMPROVING PRECISION WITH ALTERNATIVE ESTIMATES FOR THE DAILY EGG PRODUCTION RATE OF TWO SMALL PELAGIC FISH OFF CENTRAL-SOUTHERN CHILE

Dr Prof. Luis Cubillos, Department of Oceanography, Universidad de Concepción, Barrio Universitario s/n, Concepción, Chile
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The Daily Egg Production Method has been applied to common Sardine (*Strangomera bentincki*) and Anchovy (*Engraulis ringens*) since 2002, and conducted yearly since then (except in 2006). The objective is to provide estimates of the spawning stock biomass for stock assessment purposes, but precision of the conventional estimates of the daily egg production rate have been lower, with coefficient of variation that have fluctuated between 0.28-1.65 and 0.06-2.62 for Anchovy and Sardine, respectively. After 11 year of applying the daily egg production method for common Sardine and Anchovy off central Chile, it is absolutely necessary to improve the precision of our estimates, particularly daily egg production (Po) and mortality rates (Z). A stratified sampling design has been applied to collect egg samples from two independent strata (Central and South sectors). The egg abundance in one of the stratum (i.e, Central) has been very variable year to year for both the species, inflated the variance of Po. The other one (South sector), is a recurrent spawning site and therefore usually Po estimates have better precision. In this contribution, we apply two methods to dealing with estimation of Po and Z for stratified sampling designs in which egg abundance is low and variable in one of the strata. One of them was based on estimates of the ratio of egg abundance in the low-density stratum to that in the high density stratum. The other method was based on Non Linear Mixed Effect Models, where the strata were considered as fixed effects, and Po and Z as random effects. We will describe details of our approach and the implementation of a simulation of the spawning to evaluate the performance of the methods.

INTRODUCTION TO EUROPEAN COLLABORATIVE PLATFORMS

Cindy van Damme (1) and Maria Manuel Angélico (2)
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International ichthyoplankton surveys in the North East Atlantic are mostly coordinated through the International Council for Exploration of the Sea (ICES). All of these surveys are coordinated and planned by their own expert group. The ichthyoplankton surveys are undertaken using the same gears and methods but until recently they were working on their own and there was little exchange of ideas, techniques, and developments between them. In 2010 a working group was created to ensure cross-fertilization between these groups. This group has now developed into an umbrella group called the Working Group on Atlantic Fish Larvae and Egg Surveys (WGALES). WGALES aims for the cross fertilization of ideas, methodologies, developments, and standardization of ichthyoplankton surveys in the ICES area as well as providing a platform from which to improve the assessments based on the ichthyoplankton surveys. The activities of WGALES are vital for the delivery of state-of-the-art ichthyoplankton surveys, ensuring high standards, and incorporating new techniques and developments for the future. WGALES now provides a forum for discussion and dissemination on matters pertaining to spawning dynamics, ichthyoplankton biology, ecology, surveys, and egg and larval production methods.

***Day 2: The European experience: benefits of collaboration***

THE DEPM FOR THE BAY OF BISCAY ANCHOVY FROM 1987 TO 2013

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The BIOMAN surveys for applying the Daily Egg Production Method to Anchovy in the Bay of Biscay started in 1987 and they have been conducted yearly since then (with the only exception of 1993). The main objective of these surveys is providing direct estimates of the state of the stock (spawning stock biomass and population age structure). However, they also aim at improving the knowledge on the spawning environment and the reproductive strategy. Especially in the last years the surveys have been broadened for obtaining additional information from an ecosystem perspective such as hydrographic characterization, other species abundance estimates, stomach content of fish species, zooplankton distribution, genetics of fish or microchemistry of otoliths. The first DEPM applications followed the methodology as described in Parker (1980) and Lasker (1985). However, several improvements have been incorporated gradually along the time series. In this presentation we will focus on the estimation of the total daily egg production and mortality rates. First we will describe in detail the current methodology for obtaining these estimates. Then we will introduce a novel Bayesian hierarchical approach trying to overcome some of the most common problems in the estimation process.

THE ATLANTO-IBERIAN SARDINE DEPM: 1988 – 2011

M. M. Angélico (1), A. Lago de Lanzós (2), P. Díaz (2), C. Nunes (1), A. Silva (1) and M. Bernal (2,3)
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The DEPM methodology was first applied for spawning stock biomass estimation for the Atlantic Iberian Sardine (*Sardina pilchardus*) by Portugal (IPIMAR, presently IPMA) and Spain (IEO) in 1988. During the nineties, through informal contacts both countries organised surveys in 1997 and 1999, in 1990 only Spain carried out a survey that covered part of the area. From 2000 onwards methodological and analytical developments and effective coordination have been undertaken under the auspices of ICES Study/Working Groups and the estimates produced (triennially) used in assessment modelling. To obtain spawning stock biomass estimation the DEPM involves surveying directed at egg abundances and spawning area definition, for daily egg production determination and adult sampling for daily fecundity calculation. Icthyoplankton samples, and simultaneous CTD(F) casts, and fishing hauls are undertaken over the whole spawning region. In recent years the data collection during the DEPM surveys has been enhanced and diversified, not only to promote improvement in the method but also to take advantage of the comprehensive coverage of the pelagic environment and further the understanding of the ecosystem. This presentation reports on methodological developments achieved along the years and addresses current analytical issues related in particular to mortality and egg production estimation. Bias mortality estimates can arise from problems with surveying or difficulties fitting the mortality curve model, in particular related to the lack of observations at both tails of the egg distribution, very young and very old eggs are often poorly represented in the plankton samples. The reliability of mortality estimates per strata and for each year separately is discussed alongside a reanalysis of average mortality estimation obtained via the external mortality modelling approach described by Bernal et al. (2011).

MACKEREL SPAWNING STOCK BIOMASS: COMPARING ANNUAL AND DAILY EGG PRODUCTION METHODS

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Since 1977 triennial egg surveys have been carried out in the North East Atlantic to estimate Mackerel (*Scomber scombrus*) spawning stock biomass (SSB). Despite evidence showing that Mackerel is an indeterminate spawner the triennial egg survey was designed as an Annual Egg Production Method (AEPM) survey. In 1992 and 1995 the Mackerel egg survey working group tried to carry out a Daily Egg Production Method (DEPM) survey. For technical reasons carrying out the sampling for the DEPM was considered to be an inappropriate method for Mackerel and publications were published stating Mackerel was a determinate spawner and the AEPM an appropriate method to estimate SSB. Lately more evidence shows the indeterminacy of Mackerel and questions arise how appropriate the AEPM really is for Mackerel. During the 2013 egg survey samples for both the AEPM and DEPM were collected in order to compare the two methods for estimating Mackerel SSB. Results of both egg productions methods, including variance estimations, will be presented to test the appropriateness of either method for Mackerel SSB estimation in the NE Atlantic.

OVERVIEW OF STATISTICAL APPROACHES; SOUTH AUSTRALIAN SARDINE FISHERY

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The statistical methodologies involved in estimating the spawning biomass of Sardines in South Australian waters via DEPM closely mirror efforts from similar fisheries around the world. The relevant data that we possess requires careful considerations due to significant over-dispersion and low counts. In this talk, I will present an overview of the application of these methodologies to our data and a brief critical assessment of their performance, with the goal of better determining the most suitable analysis techniques and the confidence that can be placed in spawning biomass estimates associated with such.

***Day 3: Looking to the future: opportunities for improvement***

THE ADULT SURVEY OF THE DEPM: STILL ROOM TO IMPROVE

Kostas Ganias
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The presentation will cover two of the most common problems in the adult survey of the DEPM: the unbiased estimation of spawning fraction, S, and the lack of hydrated females in measurements of batch fecundity, Fb. Concerning S several pitfalls and bias issues will be discussed mainly concerning the application of the postovulatory follicle method. Despite its popularity the method can be quite inaccurate when its criteria are applied to other species and populations without prior validation. Four important sources of bias in the application of the method are identified: technical bias related to POF staging, bias in POF ageing, sampling bias and bias in the estimation of spawning fraction. Bias in POF staging is mostly due to incorrect use of histological criteria, artefacts in histological preparations and visual illusions in routine histological scorings. Since the histolomorphology of POF degeneration is similar for most fish species, bias in POF ageing is mostly linked to inter- and/or intra-specific differences in POF resorption rates. Lack of daily spawning synchronicity in some fish populations may also cause biased POF ageing. Sampling bias is caused whenever spawning stages are not evenly distributed in the surveyed fish population. For example, formulation of spawning aggregations or size dependency in spawning frequency may cause gear related over- or under-estimations of the spawning fraction. Apart from all these potential bias factors the method is quite costly and labour intensive because it needs large number of adult samples, much histology and many work-hours from experienced personnel. In that respect, the development of alternative methodology for estimating spawning frequency seems worthwhile. Concerning Fb, the presentation will deal both with the simplification of the traditional 'hydrated oocytes' method and with the inclusion of earlier ovarian stages in batch fecundity measurements. Specifically, an automated procedure is presented which uses micrographs of ovarian whole mounts to recognize, separate and count only oocytes belonging to the spawning batch in both hydrated and non-hydrated fish ovaries. The procedure bases on the ability of most image-analysis software to count and measure objects in binary or thresholded images. This procedure can be applied both in hydrated ovaries and in ovaries of previous developmental stages. Apart from increasing the number of samples for fecundity measurements the automated procedure could contribute in saving time and work-load since oocyte counts could be performed 5 to 8 times faster compared to direct counting under the optical microscope. Furthermore, applications of this method may provide large archives of digital micrographs to which someone can easily come-back for posterior analysis without depending on the status of stored biological material and the existing laboratory infrastructure (precision gauges, stereoscope, etc.).

ADVANCING TECHNOLOGIES MAY ENHANCE ESTIMATION OF DAILY EGG PRODUCTION

Mike Steer (SARDI), Joanne Dias (Fisheries WA), Richard Saunders (QDPI), Jeremy Lyle (IMAS) and Tim Ward (SARDI)

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Difficulties associated with the reliable identification and accurate aging/staging of eggs have constrained the application of the DEPM to a limited number of species. Recent advances in molecular techniques have simplified egg identification and potentially increased the number of species to which the DEPM could be applied. This talk will compare the advantages and disadvantages of the range of molecular techniques currently being used, or under investigation, to identify eggs for application of the DEPM. Particular consideration will be given to potential use of new technologies to age/stage eggs.

***Day 4: Ecological issues: trophic impacts, interactions with protected species and localised depletion***

MANAGING FOR ECOSYSTEM EFFECTS OF FISHERIES FOR SMALL PELAGIC SPECIES

Tony Smith, CSIRO, Australia

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There has been considerable interest lately in the ecological role played by small pelagic species, both as a trophic pathway from secondary production to higher trophic levels and for the possible impacts of fishing them on key predators. This talk will summarize key recent findings from recent studies on these issues and will also discuss some of the proposed changes in management strategies arising from dealing with such issues.

CCAMLR'S ECOSYSTEM APPROACH TO MANAGING FISHERIES ON FORAGE SPECIES: MAINTAINING PRECAUTION IN AN EXPANDING KRILL FISHERY

Andrew Constable and Jessica Melbourne-Thomas

*Australian Antarctic Division, Antarctic Climate & Ecosystems Cooperative Research Centre*

The Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is widely recognised as a progressive international Commission with a primary responsibility for the conservation of the Southern

Ocean marine ecosystem. In its convention and established practice it has the attributes of a regional fisheries management organisation. The foundation objectives (Article II) make special reference to the requirements to be met by fisheries. These objectives were designed principally around the dominant prey species in the Southern Ocean, Antarctic krill (hence the oft-used term, 'krill convention'). Timely decision-making is difficult in a consensus environment. The introduction of a precautionary decision rule made it possible to decide on catch limits for krill with limited data, while generally allowing for the needs of krill predators. A 'trigger level' was established to cap the fishery at a much lower level than the full catch limit (~10%) that was considered to not impact predators. It will remain in place until such time as a feedback management procedure is established that will satisfactorily achieve the objectives for conserving krill predators and allow the recovery of whales and seals from previous overexploitation. The trigger level was considered necessary because there were, and remain, no obvious methods to avoid localised concentrations of the fishery as it expands to its full potential; such concentrations were envisaged to possibly cause major impacts on krill predators. Further, this trigger level has been spatially distributed to ensure that local catches do not impact on krill predators even at low levels. This talk will describe these measures and then elaborate on the work that has progressed since 2000 on approaches to allow the fishery to expand beyond the trigger level, taking into account the sources of data that may be available on krill, krill-predators, the fishery and the environment. A number of steps have been important in this process. First, the main areas of the current fishery were divided into small-scale management units, which reduced the size of the management areas to one more at the scale of predator foraging areas and local rather than regional ecosystem processes. Second, a consolidation of knowledge on ecosystem structure and function allowed the development of minimally-realistic models to evaluate different management approaches. Third, consideration of some candidate management approaches has occurred, including (i) a static subdivision of the catch limit amongst SSMUs, (ii) a dynamic approach to setting catch limits based on measures from the fishery, and (iii) the use of a simple food web model in which parameters are estimated from the CCAMLR Ecosystem Monitoring Program and catch limits set to take account of the desirable spatial patterns in the fishery and the requirements of predators as in Article II. A difficulty with all approaches is to gain acceptance on how to satisfactorily operationalise Article II in relation to predators and thereby establish decision rules that take account of predators explicitly. These different approaches will be described along with consideration of variations on operational objectives for predators. The most important challenge is how to take account of ecosystem uncertainty in decision-making such that the probability of achieving sustainable and productive ecosystems in the face of climate change will remain high. Some possible solutions are discussed.

ECOSYSTEM RESEARCH: CASE STUDY SOUTH AUSTRALIAN SARDINE FISHERY

Simon Goldsworthy, South Australian Research and Development Institute (SARDI), Aquatic Sciences, PO Box 120, Henley Beach, SA 5022, AUSTRALIA
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The South Australian Sardine Fishery (SASF) was established in 1991 and is now Australia's largest fishery by weight. In 2004, the SASF licence holders, the fishery managers and Australian scientists initiated a broad ecological study, which aimed to assess the impact (if any) of the fishery on the natural predators of Sardines, to determine whether an explicit ecological allocation of Sardines was required. Over a six year period, research was undertaken to determine the diets and key foraging habitats of pelagic fishes, squids, marine mammals and seabirds, which could potentially be used to assess the need for ecological and/or spatial allocations in the SASF. In addition, ecological models of the eastern Great Australian Bight were developed using the Ecopath with Ecosim software. Results provided an ecosystem perspective of the fishery, by placing its establishment and growth in the context of other dynamic changes in the ecosystem, including: the development of other fisheries; changing abundances of apex predator population and oceanographic change. The potential impacts of the SASFon high tropic level predators were investigated, particularly land-breeding seals and seabirds which may be suitable ecological performance indicators of ecosystem health. Results indicated that despite the rapid growth of the Sardine fishery since 1991, there has likely been a negligible fishery impact on other modelled groups, suggesting that current levels of fishing effort are not impacting negatively on the broader ecosystem structure and function in the eastern Great Australian Bight. However, more spatially resolved ecosystem model are required to investigate the potential for localised effects. The projects ability to resolve and attribute potential impacts from multiple fisheries, other human impacts and ecological change in this poorly understood region is highlighted by the study, and will be critical to ensure future ecologically sustainable development within the region.

MITIGATING INTERACTIONS OF DOLPHINS IN PURSE SEINE FISHERY

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The South Australian Sardine Fishery was established in 1991 and is now largest volume fishery in Australia. In 2005, an industry Code of Practice (CoP) was established to mitigate the encirclement and mortality of the short-beaked common dolphin (Delphinus delphis) in purse-seine nets. The CoP aims for world’s best practice in mitigating interactions with protected species and has been adaptively refined since its inception. Under the CoP, a working group meets quarterly to review observer and fishery logbook data on interactions, assess the effectiveness of mitigation strategies and identify potential refinements to the CoP. Skippers meetings are held every two months to discuss the effectiveness of the avoidance and release procedures and identify options for improving the CoP. Vessel-specific flowcharts documenting the role of each crew member in mitigating interactions have been developed for each vessel. Each new crew member is formally inducted to the CoP and advised of their specific roles and responsibilities in mitigating interactions with dolphins. Crew members are re-inducted to the CoP prior to the start of each fishing season. In 2011, the South Australian Sardine Industry Association initiated an industry run program to collate and disseminate data on interaction rates between working group meetings. The CoP has proven to be effective in reducing interaction rates with dolphins. In 2004-05, before the introduction of the CoP, 2,200 (95% CI 1728-2672) and 480 (260-701) dolphins were estimated to have been encircled and died, respectively, whereas in 2005-06, after its introduction, 227 (125-328) dolphins were encircled and 11 (0-34) died. In 2012-13, 275 (169-381) dolphins were encircled and 10 (0-30) died. The number of mortalities in 2012-13 was less than 3% of that recorded in 2004-05. This reduction in the mortality rates reflects the co-occurrence of several changes in fisher behaviour. The success in avoidance (search and delay) procedures in preventing encirclements has reduced the potential for mortalities. Reductions in the time taken to respond to encirclements and improvements in the release procedures (i.e. opening the net) have increased the survival rates of encircled dolphins. The success of the CoP provides evidence of the important conservation outcomes that can be achieved when effective working relationships are established between industry and scientists.

MARINE MAMMAL INTERACTIONS WITH MID-WATER TRAWLING IN THE AUSTRALIAN SMALL PELAGIC FISHERY

Jeremy Lyle, Simon Willcox and Klaas Hartmann, Institute of Marine and Antarctic studies, University of Tasmania

Concern over marine mammal bycatch in mid-water trawl operations has attracted substantial public attention and remains as a major uncertainty confronting the future development of the Australian Small Pelagic Fishery. In this study we used a trawl-mounted underwater video camera to examine (i) behavioural and operational factors contributing to marine mammal interactions and (ii) the effectiveness of seal exclusion devices (SED) in reducing bycatch mortality. Fur seals were observed inside the mid-water trawl net in over half of the monitored trawl shots. The vast majority (>85%) of interactions involved seals having entered net via the trawl mouth, the remainder used the SED escape opening to access the gear, whereas over half of the seals exited the net via the SED escape opening rather than swimming back out through the net mouth. Seals entered the trawl during all phases of the fishing operation, although interaction rates were significantly higher during the setting phase, and there was no effect of time of day in relation to the rate of interactions. Bottom and top opening SED configurations were compared, with SED configuration having no influence on interaction rates. A three-fold reduction in lethal interactions was, however, achieved by simply enlarging the size of the escape hole. Nonetheless, the mortality rate associated with mid-water trawling was high by comparison with other Australian trawl fisheries and since seal-fishery interactions appear inevitable, further refinements focused on expediting the ejection of seals are required to the SED design if mortality rates are to be reduced.

LOCALISED DEPLETION: DEFINITION, EXAMPLES AND MITIGATION OPTIONS

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Localised depletion is a reduction in the density of a fish species caused by fishing that persists over an area and time period likely to cause negative impacts on predatory species or other fisheries targeting the depleted species. Risk of localised depletion is highest for target species with low mobility (e.g. abalone) and lowest for highly mobile species (e.g. pelagic fish). Predatory species with limited foraging areas, especially central place foragers, are most likely to be impacted by localised depletion. Localised depletion is less relevant to highly migratory species or species with large foraging areas. Geographical barriers (headlands, straits) can increase the likelihood of localised depletion by limiting movement rates. A range of approaches have been used to mitigate the occurrence of localised depletion including: zoning, spatial closures and move on rules. In this presentation I present examples of measures that have been taken to addressing localised depletion in pelagic fisheries worldwide and compare these to measures established and being considered in Australia’s fisheries for small pelagic species.

***Day 4: Stakeholder forum: benchmarking Australia's fisheries science for small pelagic species against World's best practice***

A SPF INDUSTRY PERSPECTIVE ON KEY ISSUES

Gerry Geen, Seafish Tasmania, Pty, Ltd

The SPF's current quota is 35,000 t, but the catch is only 200 t. What's the problem? Fish are more mobile than the boats, and there are few offloading points and processing facilities. This limits the range of fishing operations due to fish spoilage. Cheap products produced are: bait and fishmeal. A solution would allow a freezer-trawler to operate in the fishery with the benefits of: (i) efficient operation and profitable industry; (ii) high quality frozen product for human consumption; (iii) wide-range between fishing grounds; (iv) state-of-the art technologies; and (v) easier and more effective Government monitoring. Obstacles include: (i) unrealistic information requirements by NGOs (but with a strong body of research and industry commitment to fund ongoing DEPMs); (ii) marine mammal interactions (mitigated by: top-opening SED, net bindings, autotrawl, fishing grounds; dolphin and seal management plan; further adaptation and refinement over time); (iii) local depletion – causes decreases in food supply for central place foragers/angler's catch rates (mitigated by move on rule and spatial/temporal closures). In order to have a world class fishery using freezer-trawlers, some practices are critical to have in place: (i) precautionary harvest strategy; (ii) ongoing DEPM program; (iii) best practice mitigation technologies; and (iv) package of spatial management for science, central place foragers and user conflicts.

A SASF INDUSTRY PERSPECTIVE ON KEY ISSUES

Paul Watson, South Australian Sardine Industry Association

My topic for today is the industry perspective. I had actually spent a bit of time doing a PowerPoint for this part of this forum, but between Monday and now my industry perspective's changed a bit. So I am going to wing it as best I can. The SPF and SASF have both found themselves the subject of unprecedented public interest in the last couple of years. The fishing industry is in a new space where it's the subject of political conflict. It's become political currency and it's been traded among politicians. Having been in the fishing industry for 25 years I find that really disturbing. People's lives, people's investments – everything – have been challenged. Marine parks and other pressures have seemingly demonised the Australian fishing industry, which in my view is an exemplar to the planet for primary production.

New words like social license, localised depletion - all this stuff that we'd never heard of 5 or 10 years ago have become the tools, the weapons of choice – to try and restructure how our fisheries are managed. I have learned this week that fisheries science is not an exact science. The take home message is: how are we going to utilize this information to develop tools to estimate stock levels. The spawning biomass estimate determines the fate of the fishery for the next year or two. Harvest strategies for our fishery and probably to a lot of other fisheries need to be flexible enough to accommodate that uncertainty. The harvest strategy that we've developed in South Australia captures that uncertainly. I am much happier with our harvest strategy at the end of this week then I was at the beginning. There have been sticking points but we are in a better space then we were a couple of years ago.

The SASF fishery is Australia's largest fishery by volume. My old man said to me the other day – "when you're a target someone is always going to want to hit you, and when you're a big target you are going to be bloody easy to hit'. And you look around the room today and think that is so true of these fisheries. I am sure Gerry and his team will attest to that.

The reality is though, that these fisheries will never develop without some sort of risk. At some point some of these things have to be put to the test. The Sardine fishery's had to do it; the prawn fishery had to do it. Imagine if we were trying to develop a Spencer Gulf prawn fishery right now, from scratch; trying to accommodate every risk, every hypothetical situation that might or might not occur. It would never happen. And that is what we are seeing happen in the SPF. We are in the luxurious position in the South Australian fishery that we have been able to pass through that void and pop out the other side, with some really well-structured fisheries management principles. I wouldn't like to be trying to do it now. It's a tough environment.

The one thing that nobody has talked about this week is the people. You can't have a fishery without fish, but you must have people. And I think those people can get lost in this vacuum of fisheries' management. It's sad to watch the impact that some of these decisions have on people. These people are not things or objects that can be traded. They're people's lives; they're people's personalities; they're people's passions; their identities. We are not only talking about fish we're taking about people, we're talking about communities, mortgages, kids at schools, everything. And in Port Lincoln the fishing industry has been the fabric of the community for many years and from my experience and others from Port Lincoln, confidence has been lost.

There are a few people in the room here to drive that point home. We've got second and third generation fishers. These people are not in it just for the money. It's what they do. It's their very sense of identity. And that's my message and that's my industry perspective. And that's our message from Port Lincoln. Thanks.

SMALL PELAGIC FISHERY PERSPECTIVE

Steve Shanks, Australian Fisheries Management Authority

The Fisheries Management Act 1991 (FM Act) provides the power for AFMA to regulate fishing by allowing for: the establishment of Management Plans, which are legislative instruments that set out the management arrangements for a fishery. The objectives of the FM Act and management Plans include: (i) implementing efficient and cost-effective fisheries management; (ii) ensuring exploitation of fisheries resources and related activities are conducted in a manner consistent with the principles of ecologically sustainable development (including the precautionary principle) and have particular regard to non-target species and the sustainability of the marine environment; (iii) maximising net economic returns to the Australian community from Australian fisheries; (iv) ensuring accountability to industry and the community in the management of fisheries resources; and (v) achieving government targets in relation to cost recovery in the fishery. The SPF is divided into two zones (East and West), and there are four target species: Jack Mackerel (*Trachurus declivis*, *T. murphyi*), Blue Mackerel (*Scomber australasicus*), Redbait (*Emmelichtys nitidus*) and Australian Sardine (*Sardinops sagax*). The SPF Harvest Strategy uses scientific outputs to determine exploitation rates/ levels for each stock in the two zones of the SPF based on three tier levels determined by information available on a stock. Environmental impact is mitigated through Ecological Risk Assessment (ERA) and Ecological Risk Management (ERM) reports, a Bycatch and Discarding Work Plan and export permit as an approved Wildlife Trade Operation (November 2012 to April 2015).

SOUTH AUSTRALIAN SARDINE FISHERY

Brad Milic, Primary Industries and Regions South Australia

The objectives of the Fisheries Management Act 2007 are: (i) conserve and manage aquatic resources protect aquatic habitat and ecosystems; (ii) share access so the whole community gets the maximum possible benefit; (iii) foster recreational & commercial fishing activities; (iv) encourage stakeholders to participate in decision-making; (v) equitable allocation of resources between users; and (v) efficient & cost effective management. Fishery management plans have been developed for all major fisheries and must be consistent with the objectives of the Act. They also must set out a process to meet the objectives of the Act. A Minister must manage the fishery in accordance with the management plan. Management plans include: (i) fishery description (biological, economic and social); (ii) ecological risk assessment of effects of fishing; (iii) goals and strategies to address risks; (iv) harvest strategy; (v) outline co-management arrangements; (vi) allocate shares of the resources; (vii) specify stock assessment and research; and (viii) set the term of the management plan. Ecological risks of the effects of fishing are undertaken using National ESD Reporting Framework for Australian Fisheries. South Australia is currently developing a harvest strategy policy based on the '*National Guidelines to Develop Fishery Harvest Strategies*' (FRDC Project 2010/061). Policy for co-management of fisheries in South Australia describes responsibilities of both management and industry.

MARINE STEWARDSHIP COUNCIL: LOW TROPHIC LEVEL SPECIES

Robert Lefébure, Marine Stewardship Council

The MSC runs an exciting and ambitious program, working with partners to transform the world's seafood markets and promote sustainable fishing practices. MSC's credible standards for sustainable fishing and seafood traceability seek to increase the availability of certified sustainable seafood, and our distinctive blue ecolabel makes it easy for everyone to take part. Standards meet the world's toughest best practice guidelines and are helping to transform global seafood markets. The issue of how to deal with ecosystem impacts of Low Trophic Level (LTL) fisheries is always recognised but guidelines are unclear. The MSC set up an LTL working group in 2009 to reviewed best practice guidelines. The review undertook wide stakeholder engagement, and commissioned a scientific study to use ecosystem models to explore trophic consequences of depleting LTL species. For key LTL species the default harvest strategy must either maintain 75% of $B_0$ or have a target exploitation rate of 0.5 FMSY or 0.5M. These levels can be adjusted using the filters of: A) a large proportion of the trophic connections in the ecosystem involve this stock, leading to significant predator dependency; B) a large volume of energy passing between lower and higher trophic levels passes through this stock; and C) there are few other species at this trophic level through which energy can be transmitted from lower to higher trophic levels, such that a high proportion of the total energy passing between lower and higher trophic levels passes through this stock (i.e. the ecosystem is 'wasp-waisted). For non-key LTL species, the minimum default TRP is 40%$B_0$ and the minimum allowed LRP is 20% $B_0$ or half TRP. For key LTL species at SG60 the default TRP is15% above BMSY, and at SG80 the default TRP is 75% $B_0$. The 'Ecosystem needs' LRP is at half the level of the TRP (37.5% $B_0$ if default used at SG80, or other level). About 80 LTL stocks have been identified globally thus far; 19 are key LTLs based on these criteria.

A RECREATIONAL FISHING SECTOR PERSPECTIVE

Graham Pike, Recreational fisher

This 'workshop' cannot and should not be regarded as a 'stakeholder' workshop. The late notice meant that recreational fishing sector organisations and members could not re-organise their schedules and commitments to enable them to participate in this week's technical forum and in today's activities.

In 2000, Recfish Australia launched a major public campaign related to large scale harvesting of Blue or Slimy Mackerel (*Scomber australasicus*) in the Jack Mackerel Fishery. Research undertaken on Blue Mackerel and other species resulted in a Management Plan for the Small Pelagic Fishery to be established in 2009. The arrival in Australia in August 2012 of a large Dutch-owned and operated factory-freezer vessel was opposed by a large number of ordinary Australians. The recreational fishing sector and the conservation movement voiced concerns that research conducted in the SPF was inadequate to justify the operation of the factory-freezer vessel. Some academics and scientists declared that social license was 'lost'; however, social license was never gained. Politicians listened to the voters and the federal government imposed a ban on super-trawlers. There has been unprecedented lack of impartiality, independence and circumspection in the way many academics, scientists and fishery managers defended inadequate data, imperfect scientific methodology and the super trawler venture itself. This forum and workshop, together with continuing substantial federal government expenditure to determine what scientific research is needed to protect the SPF and its ecosystem against overfishing, or worse, by factory freezer vessels, is vindication of our position and testament to the fact that we needed more research and data then, and we still need more now. The objectives for this fishery must include maintaining abundance levels to support the large populations of pelagics and others that depend on the resources of the SPF as food sources, particularly in areas important to the recreational fishing sector. Research, science and data needed now to protect SPF stocks and their abundance in that ecosystem include: 1) commitment to ongoing DEPM surveys across the SPF at Tier 3 of the current SPF Harvest Strategy; 2) recent, continuing, regular and geographically comprehensive DEPM surveys (computer modelling is unacceptable as a substitute); 3) commitments that fishing-independent research and data will continue to precede development and management decisions in the fishery; 4) sound information on fish movements within SPF stocks to inform management on localised depletion and other issues; 5) management, including measurement or identification markers, to reduce the risk of localised depletion; 6) commitment to continuing and comprehensive observer coverage on all factory-freezer vessels; 7) greater transparency of fisheries management (AFMA's five boat rule is unacceptable), and 8) re-affirmation that recreational fishing and ecosystem considerations have equal weight with commercial considerations in relation to the SPF.

ONE CONSERVATION PERSPECTIVE

Alistair Graham, Conservation advocate

“I am currently employed working for WWF International on ocean government’s reform and was asked by WWF Australia to come here because of the slightly difficult situation, which is that the conservation stakeholders for this fishery have decided not to come, not because of any short notice but because of a build-up, an accumulated concern, about how the management of this fishery is going. The main concern here is the loss of non-industry stakeholder confidence in the management of the fishery. One of the really big concerns is the concept of economic value. There is a substantial economic value in the SPF in Australia right now, and that is made up of three components: the recreational fishery, its tourism and recreational value for people other than fishers, and most importantly, the value of those species that depend on the small pelagics for their existence. Fishers get obsessed with the commercial value and institutions tell you that this is important but in the broader community it is not. Here, you've got the same problem that crops up in many situations of having crusading scientists who keep telling you that it's alright. These issues go far beyond the fishery in question, but to how our society at large comprehends, trusts and responds to what the scientific community are saying. With respect to fisheries in Australia, my view is we actually have a serious, systemic problem, which was delightfully illustrated by the expert panel on this enquiry about the *Margiris*. In Hobart, the panel invited everybody in to have a chat: the scientists, managers and fishers all had one session; the conservationists had another session, and the recreational fishers had another session. This clearly articulated the sense to which everyone understands that the science community, the fisher community and the manager community work together as a mob or as a 'cabal' (a group of players, a subset of players who operate at the margins of what is legal and proper to do). When the cabal gives us no option but to go to parliament and change the rules of the 'game', that's what we do. The *Veronica* was half way across the Indian Ocean from South Africa and turned around in mid-stream. The conservation sector has a stakeholder representative on 5 or 6 different fishery bodies in the Tasmanian and Federal jurisdictions. This small pelagic thing has got out of control. The cabal could not hold this representative in the stakeholder forum. That is the principal reason why we have the political mess going on right now. That the other players couldn't sit down and sort this out around the table completely bemuses me. I want to be really clear about this, that kind of political setting boundaries isn't going to help with that insider conversation. I think that AFMA, as the federal management agency, needs to have a really good look at itself. It was set up as a co-management authority and that the political system gives it a fair degree of devolved authority to go off and do stuff with a co-management mandate - that is to say: get together with the industry and sort things out. Co-management had a very narrow objective. A decade or so ago the authority thing was made a commission. We, the stakeholders, who are outside of the co-management approach thought 'this is good, we'll see some change here'. And all of a sudden nothing happened. This agency is basically deaf to non-industry things. I had the great privilege of being invited to go along to an AFMA senior management workshop, which the previous director Glen Hurry used to have every year. I was speaking under a spot called 'Views from industry' because they didn't have any framework for talking to anybody else. I can't tell you as an outsider how frustrating this is. One of the issues I work on personally is seabirds: trying to get AFMA to tell you what the performance is of vessels in fisheries with respect to seabirds. We don't even bother to ask now, we just ask questions in parliament. What I was going to leave you with is that if you really believe you want stakeholder engagement, there are two things you have to do. One, you have to do the economic evaluations, so you actually comprehend how important those stakeholders are at the level of the Australian economy and society. Two, you actually have to be real about wanting to involve them, and you shouldn't underestimate how hard this is in terms of the re-education that has to go on within institutions"

WWF AUSTRALIA: CONSERVATION PERSPECTIVES ON SMALL PELAGIC FISHERIES

Joanne McCrea, World Wildlife Fund

WWF supports sustainable fishing that is (i) ecosystem-based managed, (ii) effectively regulated and enforced, and (iii) that does not damage sensitive/vulnerable habitats, ecosystems, biodiversity or populations of target and non-target species. LTL species can operate in an ecologically sustainable way, just like many other fisheries. Why should we be concerned about LTL Fisheries? LTL fisheries constitute one third of total world catch. LTL species, like any others, can be overfished. Overfishing can be exacerbated by responsiveness to oceanographic conditions and cycles and can cause potential ecosystem impacts by reducing food availability of higher trophic level predators. Forage fish are one of 15 Priority Commodities for the WWF Global Market Transformation Initiative. There has been a 28% decline in global biodiversity between 1970 and 2008. The Market Transformation Approach targets consumers, the supply chain and primary producers/extractors. It involves one-to-one corporate engagement with large companies on issues including wild caught seafood. The WWF position on LTL recommended aims are to: 1) prevent overfishing of target LTL populations, and 2) achieve healthy target populations in healthy marine ecosystems for all LTL-fisheries. These aims should be accomplished through: (i) precautionary and ecosystem based management approaches; (ii) Strategic Environmental Assessments, including cumulative effects; (iii) competent management authorities including governments, fisheries management bodies and RFMOs to develop roadmaps for the implementation; (iv) Rights Based Management; (v) manage according to FAO Code of Conduct for Responsible Fisheries; (vi) research and monitoring integrated into the harvest strategy; (vii) maintain the fished population at least at 75% of the spawning stock level in the absence of fishing; (viii) long-term research plans to assess the impacts of fishing on target and non-target populations and the effect on predators and other dependent species (fish, seabirds and marine mammals); and (ix) consideration of the need and value for temporal and spatial management. In an Australian context relative to fisheries management with an audience: (i) the WWF's LTL position and recommendations are relevant and applicable; (ii) the public is increasingly interested in the marine environment; (iii) generally, the public has an expectation of involvement and consultation regarding this common resource; (iv) adherence to legislative and policy requirements is not sufficient where these are not in line with society's expectations for involvement; and (v) significant proposals need to start with 'questions' not 'lines on maps'.