# 6 Localised depletion

## 6.1 Introduction

The panel's Terms of Reference require it to assess and advise on "the potential for any localised depletion of target species (arising from the Declared Commercial Fishing Activity) to result in adverse impacts to the Commonwealth marine environment, including the target species' predators protected under the EPBC Act".

As discussed in Chapter 2, and expanded on below, the panel's definition of localised depletion is a relatively simple one. Examination of the nature and extent of environmental impacts that might arise from it, and whether or not those impacts constitute 'adverse impacts', is much more complex. This complexity is exacerbated by the fact that the panel's assessment is essentially of a hypothetical Declared Commercial Fishing Activity (DCFA): a scenario subject to a range of possible spatial and temporal patterns of fishing for species that are themselves mobile and difficult to locate, despite there being some predictable patterns of schooling behaviour.

The panel's assessment of the localised depletion arising from the DCFA is structured as follows.

- Localised depletion, its meaning, potential impacts and the factors that influence whether those impacts occur, and their extent, is discussed in Sections 6.2 to 6.4.
- The potential for localised depletion to adversely affect the target species themselves is considered in Section 6.5.
- The potential impacts of localised depletion on central place forager (CPF) species, particularly those species protected under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), are discussed in Section 6.6.
- The panel's assessment of adverse environmental impacts that might arise from localised depletion by the DCFA is provided in Section 6.7, followed by advice on management measures, and on monitoring and research, in Sections 6.8 and 6.9 respectively.

## 6.2 Definition

From the panel's commissioned literature review (Rogers *et al.* unpublished), and discussions with experts and stakeholders, it is clear that there are many interpretations of localised depletion.

A number of key points arose from the panel's discussions and the literature review.

- Localised depletion is defined differently by different people and for different species.
- Localised depletion has both spatial and temporal components.
- Localised depletion could be thought of as a disproportionate and persistent reduction in abundance of a stock in a particular area.
- There is a relationship between the mobility of a species and its potential for localised depletion.
- There is a relationship between the extent of habitat preference of a species and the potential for localised depletion.
- Localised depletion can be caused by factors other than fishing.
- Fishing, even at the smallest spatial and temporal scale, causes localised depletion, but, at greater scales, may cause changes to characteristics of the target stock such as the size and age composition, distribution and genetic diversity.
- It is the level of depletion by fishing, and its persistence at a level that compromises the stock and the role of that species in the ecosystem, e.g. its trophic role, that will determine whether localised depletion constitutes an unacceptable risk to the broader ecosystem.

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- Localised depletion is difficult to detect and measure.
- Localised depletion is different from overall depletion of a stock (by fishing) and it is often difficult to distinguish between these two impacts.

The panel noted, in particular, the following description of localised depletion:

"Localised depletion occurs when local removals are greater than local production + net immigration/emigration, resulting in a local reduction in abundance compared to elsewhere and in the absence of local removals. It is a deformation of the density field of the species that may persist for a long or short time depending on the dynamics of local production + net immigration/emigration. Localised depletion happens for some period every time a fish is removed from the water." (Dr K. Sainsbury, Institute of Marine and Antarctic Studies (IMAS) *in litt.* June 2013)

In their search for relevant research and literature, Rogers et al. (unpublished) adopted the following definition:

"Localised depletion is a persistent and significant reduction in the abundance/density of a targeted pelagic species over a defined area within the range of a population that is caused by a spatial and temporal concentration of fishing."

They took into consideration localised depletion brought about by fishing alone, the space and time scales over which it took place, and whether it was of a magnitude that caused an adverse impact on the ecosystem. They did not consider depletion caused by environmental fluctuations or depletion of the stock as a whole.

The panel noted that the following factors increased the vulnerability of a species to localised depletion from fishing:

- low mobility and/or dispersal (as adults and/or juveniles) therefore slow rate of re-aggregation of survivors after removal or disruption
- schooling behaviour especially in the same or predictable locations (site fidelity) therefore high probability of detection by a fishery
- weak management controls such as high allowable catches/fishing mortality and/or high spatial concentration of fishing effort and catch.

Of central importance to the panel's assessment is whether localised depletion arising from the DCFA is likely to have adverse environmental impacts. Dr É. Plagányi, CSIRO (*in litt.* 4 November 2013) identified the following factors that may determine whether the extent of the localised depletion is likely to cause adverse environmental impacts.

- The proportion of the available biomass of each targeted species that is being caught and the current status of the stocks of those species.
- Whether fishing effort is concentrated in specific areas (or at specific times) rather than being spread more widely.
- Whether there is a substantial overlap in fishing effort/catches and important foraging grounds of dependent predators.
- Whether there are land-based predators that rely on the local availability of dense concentration of prey, because they have limited ability to travel large distances during the breeding season.
- How mobile the prey species are and whether there are transport/advective/movement mechanisms that serve to replenish prey that might otherwise become depleted in an area.
- Which and how many alternative prey types are available in the area.
- Whether there are any technical interactions and whether fishing vessels themselves might disrupt prey in the foraging grounds of a predator, with a resultant positive or negative impact on a predator in addition to any impact from reducing the abundance of prey through fishing.

What is clear is that in defining exactly what is meant by localised depletion in the context of this assessment, the species of concern, the cause of the depletion, the scale of the depletion, and the nature and extent of any adverse impacts from that depletion must be clearly articulated.

It became apparent to the panel that the term 'localised depletion' has been used in the context of the debate about the introduction of a large mid-water trawl freezer vessel into the Small Pelagic Fishery (SPF) in ways that may confuse localised depletion, as defined by the panel, with overall stock depletion or with overfishing. It is important to this assessment that localised depletion is not confused with overall depletion or with overfishing.

Dr K. Sainsbury, IMAS (*in litt.* June 2013) noted that overall depletion combined with the density-dependent habitat selection that is common among pelagic fishes will result in a range contraction that may look the same as localised depletion. To explain fluctuations observed in anchovy *Engraulis mordax* populations in the northern Californian Current, MacCall (1990) developed a density-dependent habitat selection model known as the 'basin model'. The principle underlying this model is that, as a population increases, it spreads into more marginal or less desirable habitats, like a fluid filling a basin, but as it falls, the population contracts to core or more preferred habitat. Species have degrees of mobility analogous to degrees of viscosity (or 'stickiness'); the more mobile the species, i.e. the less viscous or more free-flowing, the quicker the response and movement. Bertrand *et al.* (2004) derived a different habitat-based model in which anchovy concentration or density increases in the preferred habitat as the habitat quality increases. This has been demonstrated in sardine and anchovy populations off California, Peru, South Africa and Japan (Barange *et al.* 2009) where area of occupation and packing density increased with population size.

A well-known Australian example of a species range contraction is that of southern bluefin tuna *Thunnus maccoyii* (SBT). As the population declined to about 5 per cent of the virgin spawning biomass from global over-fishing (Commission for the Conservation of Southern Bluefin Tuna (CCSBT) 2011, Polacheck 2012), the population contracted away from the coasts of Australia and New Zealand, illustrated by the absence of juvenile SBT from coastal New South Wales (NSW) where it had been present prior to the mid-1990s. Aerial surveys over the past decade in the Great Australian Bight (GAB) also provided evidence of the contraction of juvenile SBT to the eastern GAB (Basson *et al.* 2012). However, there is anecdotal evidence that juveniles of a smaller size than typical have been observed migrating into southern Tasmanian waters over autumn in recent years (Dr S. Tracey, IMAS pers. comm. 14 August 2014), indicating strong recruitment following introduction of tighter international management and aided by favourable oceanographic conditions sweeping across southern Tasmania waters. The mass mortality of Australian sardines *Sardinops sagax* in southern Australia, particularly in 1998–99, could be classed as an example of range contraction not caused by fishing. Sardines also disappeared from NSW waters, contracting back to Victorian waters where catch rates around Lakes Entrance remained high (Stewart *et al.* 2010). In following years, sardines were gradually observed extending northwards again as populations improved.

Therefore, it is important to note that while localised depletion and range contraction caused by fishing or other factors may look the same, especially to land-based predators and even fishers, the mechanisms that cause them are fundamentally different. In a range contraction, local habitat would be abandoned by the species even if there were no localised fishing, whereas localised depletion is caused and maintained by localised fishing (Dr K. Sainsbury *in litt.* June 2013). This distinction is important to the panel's assessment of impacts from any localised depletion.

The panel found only limited examples of studies of the impacts of localised depletion of small pelagic species. Rogers *et al.* (unpublished) were unable to find cases of localised depletion studies within the SPF and only limited examples globally. Some examples are provided in Box 6.1. The panel noted that all of these examples relate to purse seine fisheries for small pelagic species.

# Box 6.1 Examples of localised depletion effects in fisheries for small pelagic species

#### Scads and mackerel in the Java Sea

A study by Cardinale *et al.* (2011) demonstrates serial depletion, a series of consecutive localised depletions, over a period of 20 years, in a purse seine fishery targeting scads and mackerels (*Decapterus russelli, D. macrosoma, Rastrelliger kanagurta* and *Selar crumenopthalmus*) in the Java Sea. This fishery is driven by market forces and lacks any management that would limit exploitation. There were upward of 500 boats operating in the early part of the study period declining to below 200 in the previous four years, but their time at sea was increasing as they expanded into more distant grounds when catch rates dropped on previously exploited grounds. The fishing grounds for the main target species were sequentially depleted with distance from fishers' home port. Cardinale *et al.* (2011) concluded that the genetic studies of *D. macrosoma* and *D. russelli* suggested population substructuring resulting from 'philopatric' behaviours, i.e. those which cause a species to return to its home area such as for breeding, and lack of management, contribute to the risk of depletion. The rate of exploitation in this fishery was unknown as were ecological impacts.

#### Anchovy in Humboldt Current off Peru

A similar pattern of progressive depletion of resources was found in the purse seine fishery on anchovy *Engraulis ringens* in the Humboldt Current off Peru, but the impact was detected on the foraging distances of Peruvian boobies *Sula variegata*. For this land-based bird the critical issue is not necessarily just of global depletion but also of localised depletions at a critical life-history stage such as breeding and rearing of chicks. In a tracking study of boobies and their foraging patterns in the anchovy fishery, Bertrand *et al.* (2012) concluded that the birds needed to forage progressively further afield as prey were depleted by intense fishing in their immediate region. More recently, Bertrand *et al.* (2012) note that the fishery management has changed from open access to quota-managed; catches are now spread, allowing the fish to redistribute and avoid localised depletion; and a National Reserve has been declared to protect the colonies, including a 3.7 kilometre (km) marine zone which, however, was not thought adequate to protect the foraging zone of seabirds.

#### Atlantic menhaden in Chesapeake Bay

Localised depletion of Atlantic menhaden *Brevoortia tyrannus* in Chesapeake Bay, USA, was also suspected but not proven. This purse seine fishery operates on the north east-coast of the USA. More than 100,000 tonnes (t) per year were taken annually up to 2006 when a total allowable catch (TAC) was set at approximately 100,000 t. The species is not considered overfished. Atlantic menhaden spawns off the coast but larvae recruit into nearby bays and site fidelity is suspected (Haddon 2009). Rogers *et al.* (unpublished) found that there was no clear evidence for localised depletion nor empirical evidence to attribute negative impacts on striped bass *Morone saxatilis*, bluefish *Pomotomas saltatrix* and osprey *Pandion haliateus* to localised depletion of menhaden.

#### Summary: interpretation of localised depletion

- For the purposes of its assessment, the panel interpreted localised depletion as a spatial and temporal reduction in the abundance of a targeted fish species that results from fishing.
- Localised depletion is an inevitable consequence of fishing so that whenever fishing occurs there will be a local depletion of target (and non-target) species.
- Localised depletion should not be confused with range contraction or overall stock depletion.
- The central issue for the panel's assessment was whether the fishing activity of the DCFA could be concentrated enough, both spatially and temporally, to cause a localised depletion of the target species sufficient to cause adverse environmental impacts to the Commonwealth marine environment.
- Whether or not such adverse impacts occur will depend on a wide range of factors.
- There are limited examples of studies of localised depletion of small pelagic species.

## 6.3 Potential impacts

The panel's assessment of localised depletion requires it to identify what adverse environmental impacts there might be, but beyond that, there is a need to consider what impacts are of most concern, when that impact becomes unacceptable, and how to detect, quantify and assess those effects.

The extent to which an impact is adverse (harmful) depends on the target species' resilience to impact and the type and scale of the impact. Fishing tends to change a population's age and size structure, reproduction and genetic diversity (Jennings *et al.* 2001, Walters and Martell 2004), so it is the degree of fishing pressure combined with the species' resilience that will determine the severity of impact. The most severe impacts of direct removal from fishing on the target species could result in local extinctions e.g. several species of sharks and large fishes from south-eastern Tasmania during the 1900s (Last *et al.* 2011) or in extreme cases, whole population collapses e.g. Icelandic spring-spawning herring *Clupea harengus* (Beverton 1990). Recovery, if possible, depends on the species' reproductive capacity or even genetic diversity (Beverton 1990) but environmental variability and continuing fishing pressure will affect rates of recovery.

Impacts of fishing 'target' species on other species may be direct, i.e. arising from being coincidentally caught in the fishery, or indirect, i.e. through changes in the food web or habitat modification. Species that are already threatened may be further impacted by fishing if taken as bycatch, particularly if they are available to several fisheries, e.g. sharks and elephant fish caught in both trawl and gillnet fisheries and fur seals caught in mid-water and demersal trawl fisheries. Cumulative impacts from multiple fisheries and other sources are recognised but often difficult to assess in data-poor fisheries (Moore *et al.* 2013).

Indirect impacts are commonly non-intuitive, arising from the complex web of predator-prey interactions, often onceremoved from the direct target species, and the strength of those interactions. For example, increases in abundance might result from release from predation or competition for the same prey resource; species may expand to fill a niche or habitat which had been unavailable previously, e.g. alternation between sardines and anchovies in the Benguela Current upwelling system (Cury and Shannon 2004); or the population may decline if predation mortality increases from predators unable to find their preferred prey. Dependent predators may even starve, e.g. seal populations in northern Benguela were reduced by 30 per cent during the mid-1990s in response to environmental anomalies and consequent extensive declines in fish biomass (Cury and Shannon 2004). Predators may switch to other prey that may not be as well-suited to their nutritional needs—coined the 'junk food hypothesis' by Alverson (1992), describing the hypothesis for the decline in the western stock of Steller sea lions *Eumetopias jubatus* in Alaska—resulting in reduced breeding success and subsequent population decline. Examples of such events include sandeels and kittiwakes in the North Sea (Rindorf *et al.* 2000, Frederiksen *et al.* 2008); sprats and common terns in Firth of Forth, Scotland (Jennings *et al.* 2012); and juvenile rockfish and murres, guillemots and auklets in the Californian Current (Field *et al.* 2010).

Adverse effects from direct fishing impacts, at a broader ecosystem level, could be as severe as degradation of biodiversity such as that occurring at a global scale (Worm *et al.* 2005), resulting in instability, cascading trophic effects (Scheffer *et al.* 2005, Coll *et al.* 2008, Baum and Worm 2009, Coll *et al.* 2009a, Coll *et al.* 2009b) and proliferation of invasive or 'break-out' species (Bakun and Weeks 2006) such as jellyfish (Jackson *et al.* 2001). Whether these types of effects could be seen at a 'local' scale is the question. Interwoven with the effects of fishing are those of natural environmental fluctuations and climate change, which are not inconsequential but difficult to disentangle. Variable environmental conditions have contributed significantly to dramatic, small pelagic fishery collapses worldwide over the past several decades and are discussed in many scholarly reviews (see, for example, Beverton 1990, Schwartzlose *et al.* 1999, Cury *et al.* 2000, Jackson *et al.* 2001, Freon *et al.* 2005, Mullon *et al.* 2005, Pikitch *et al.* 2014). While regime shifts are largely thought to be responses to oceanic and climate shifts, fishing has contributed to a regime shift in the Namibian ecosystem (Cury and Shannon 2004). Management of small pelagic fish therefore needs to take into account natural environmental variability as well as the impacts of fishing.

Compounding the difficulty of managing for environmental variability is the prospect of climate change which increasingly presents a significant threat to fisheries (Hobday 2010, Hobday 2011). Cheung *et al.* (2009) explored the potential effect climate change could have on more than 1000 species of fish and invertebrates. They found local extinctions and species invasions in many regions were possible and a 60 per cent turnover in present diversity was possible. Hobday (2011) similarly demonstrated the possibility of physical changes in east Australian waters by simulating climate-change scenarios from the Intergovernmental Panel on Climate Change in a finely-resolved Bluelink model nested within the broader CSIRO Mk 3.5 global climate model. Fulton (2011) predicted that, as a result of climate change, there will be "winners and losers" and some surprises. There have already been changes in the distribution of Tasmanian fishes as a result of recent warming in the local marine environment (Last *et al.* 2011).

At a more fundamental level of the food web, Kelly (2014) found that the zooplankton off Maria Island, Tasmania has been influenced by intrusions of the warm subtropical waters of the East Australian Current (EAC) in recent years, resulting in not only a higher abundance of copepods, but also changes in composition of the zooplankton. Calanoid copepods are a dominant prey for redbait *Emmelichthys nitidus* (McLeod *et al.* 2012) and are predicted to continue to thrive under warmer conditions hence favouring redbait. The flow-on effects of increased copepod abundance could also result in hotspots for copepod predators such as whales or tuna but also shift the spring bloom, potentially causing mismatches in phytoplankton and zooplankton availability for larval fishes. The transport of primary productivity between inshore and offshore areas is critical to the survival of marine species and the EAC presents a partial barrier to onshore transport but entrains waters offshore particularly where the currents diverge from the coast (Condie *et al.* 2011). Blue mackerel *Scomber australasicus* spawn in these areas of divergence aiding dispersion of larvae. In the GAB the Leeuwin Current tends to have the opposite affect i.e. eggs and larvae of sardine and anchovy are retained inshore.

Kelly (2014) suggests that there is a continuing warming trend and intensification of the EAC which may alter these transport systems and the dispersion of eggs and larvae of marine species, but also ultimately the composition of the ecosystem from phytoplankton through to fish. The panel also heard that the present oceanographic regime in the Tasman Sea has been vacillating for decades but that present indications are it will shift permanently to a new state (Dr V. Lyne, CSIRO pers. comm. 4 July 2013).

## 6.4 Factors influencing the extent and impacts of localised depletion

## 6.4.1 Scales of depletion and persistence

The temporal and spatial scale over which the fishing activity occurs is pivotal to whether adverse environmental impacts will arise from localised depletion. A single event is unlikely to cause an impact unless the effect is persistent, i.e. the effect of the removal remains long after the removal, as might occur if the target species was so immobile that the 'hole' cannot be readily filled, e.g. abalone (Prince 2005), chitons (Salomon *et al.* 2007) and crab and shrimp (Orensanz *et al.* 1998). Dr Eva Plagányi, CSIRO (*in litt.* 4 November 2013) noted that "... we have considered the distribution of fishing effort as being important when considering relatively sessile resources such as abalone and sea cucumbers, but not when considering more mobile fish stocks". For small pelagic fishes, it is more likely that fishing would need to be constant, or at least at a rate of removal that would lower the species' ability to re-aggregate or repopulate the area in some way, for adverse environmental impacts to occur.

Whether the localised depletion occurs as a result of one or many boats is irrelevant according to international and Australian fisheries managers and scientific experts interviewed by the panel. Vessels of a smaller capacity tend to concentrate effort around their home ports because their ranges are restricted by their limited fish handling and storage facilities, and fuel and provisioning capacity. A fleet of many smaller vessels has the potential to create localised depletion if the fishing intensity is spatially and temporally dense. It has been suggested that localised depletion of jack mackerel *Trachurus declivis* occurred off east Tasmania in the 1980s. For example, Environment Tasmania (2014) states: "It is believed that localised depletions have already occurred around Tasmania. Large surface schools of jack mackerel were once common off Tasmania until they were targeted by trawlers more than 20 years ago. These surface schools soon disappeared and have not been seen since" and it has been stated that "earlier annual capture records from the Tuna Club of Tasmania have shown that localised depletion has occurred in the past when purse seine trawling occurred off the East Coast of Tasmania earlier this century" (Mr K. Antonysen *in litt.* October 2012). This view is also supported by a recent survey of offshore recreational fishers in Tasmania for whom the biggest issue is "the perceived or historically realised overfishing" (Tracey *et al.* 2013).

In the 1980s, a fleet of six to seven small purse seiners (24–47 metres (m) length overall; 100–500 t hold capacity) operated in the jack mackerel fishery (Williams *et al.* 1986, Williams *et al.* 1987). These vessels were small but with the aid of an aerial spotter, landed nearly 118,000 t in four years (Williams *et al.* 1987, Williams and Pullen 1993). The majority of the effort was concentrated between Maria Island (off the home port of Triabunna) and Tasman Peninsula and within state waters (Williams *et al.* 1987). The fishery then declined and fluctuated over the next two decades. The surface schools of fish had largely disappeared and the sub-surface schools were harder to find and target. The 'disappearance' of fish has been often attributed to localised depletion resulting from fishing, as discussed in preceding paragraphs, but the most significant underlying cause was linked directly to a change in factors that underpin the surface-schooling behaviour of the fish, i.e. changing oceanographic conditions affecting the availability of their major prey, krill *Nyctiphanes australis* (Harris *et al.* 1991, Harris *et al.* 1992).

Jack mackerel caught from the surface schools by the fishery were found to be feeding on swarms of krill (Williams and Pullen 1993). Krill will form dense schools of 100–200 m diameter when abundant in waters of about 15°C (Harris *et al.* 1992). The reason that 15°C water is important is because this is the temperature at which nitrate appears in the water column over summer, supplying nutrients to phytoplankton production (Harris *et al.* 1992). Krill feed on large diatoms, detritus and copepod faecal pellets (Harris *et al.* 1991, Harris *et al.* 1992). Diatoms and large phytoplankton dominate the plankton community in cooler, more productive water conditions, whereas smaller copepods dominate in warmer less productive conditions. The zonal westerly winds normally entrain cold productive water up the Tasmanian east coast shelf waters, favouring krill, but after 1987 these winds were weak. This period of weak westerlies and the intrusion of warm sub-tropical waters of the East Australian Current led to the shelf waters warming to 20°C and productivity dropped. The waters became oligotrophic leading to domination of small copepods and elimination of large zooplankton, including the krill. Consequently, the fish had moved to the southern-most tip of Tasmania beyond the reach of the purse seine fishery at the time. Furthermore, similar warming events have occurred in the past: once in the 1950s (Harris *et al.* 1992) and again in the 1970s. When the latter event occurred, the jack mackerel fishery on the east coast collapsed but extensive shoals of fish were sighted by aerial surveys off the south-west coast of Tasmania in 1976 (Williams 1981).

## 6.4.2 Vulnerability of SPF target species to localised depletion

Small pelagic fishes are those that are relatively small; abundant; form schools; are short lived; mature early and are highly fecund; are subject to high inter-annual recruitment variability; and are usually planktivorous, or largely so (Alheit *et al.* 2009, Pikitch *et al.* 2014). These biological characteristics make them highly sensitive to changes in ocean climate reflected in often dramatic changes in abundance (Alheit *et al.* 2009) but also provide a level of resilience. Small pelagic species are important in the diets of predators.

#### Productivity

The small pelagic fish assemblage within Australia is dominated by the smaller-sized clupeids (e.g. Australian sardines and Australian anchovy *Engraulis australis* but also includes the larger carangids (e.g. jack mackerel and Peruvian jack mackerel *Trachurus murphyi*, emmelichthyids (e.g. redbait) and scombrids (e.g. blue mackerel). The suite of target species in the SPF fishery therefore ranges from the small Australian sardine, at about 20 centimetres (cm) and six years (common age), to the medium-sized mackerels around 40 cm and 16 years. A full profile of each SPF target species is provided in Appendix 4, however a summary of relevant biological attributes is presented in Table 6.1. Australian anchovy is not an SPF managed species but is included here for comparison. Small pelagic fishes, particularly clupeids and small gadoids (cods), are generally considered to have low resilience to fishing based on the ability of the stock to replace itself, whereas larger species generally have higher resilience (Mace and Sissenwine 1993, Musick 1999). Musick (1999) developed categories of resilience/productivity based on intrinsic rates of increase,  $r_m$ , von Bertalanffy coefficients, K, fecundity, and age parameters (Table 6.1) in an attempt to assess vulnerability to 'extraordinary' mortality, such as that arising from fishing. Cheung *et al.* (2005) derived intrinsic vulnerability to fishing values, which integrated life history and ecological characteristics via a fuzzy logic system, and showed that they are more closely correlated with observed population declines. Animals with von Bertalanffy growth coefficients K of less than 0.10 and/or intrinsic rates of increase of less than 10 per cent per year, are particularly vulnerable to fishing (Musick 1999), i.e. they have a high vulnerability with 100 being the most vulnerable.

Table 6.1 Summary of biological attributes of SPF target species and Australian anchovy. 'Common' (average) size and age based on Yearsley *et al.* (1999) and observations from fishery data. Von Bertalanffy *K*, resilience/ productivity and vulnerability recalculated based on Australian data for populations where available. FL = fork length; TL = total length; SL = standard length.

SPECIES	COMMON SIZE (TL CM)	COMMON AGE	TROPHIC LEVEL	NATURAL MORTALITY	AGE AT MATURITY T <sub>M</sub>	FECUNDITY	К	R <sub>M</sub>	RESILIENCE/ PRODUCTIVTY <sup>2</sup>	VULNERABILITY
Australian Sardine Sardinops sagax	20	6	2.4	0.66 @22°C	2	10–45,000 per batch/500 eggs per g	0.47	2.34	Medium, min. pop. doubling time 1.4–4.4y	34 (low–moderate)
Redbait <i>Emmelichthys</i> nitidus	36	21	3.6	0.34 @8°C	2—4	186 eggs per g	0.22	1.06	Medium, min. pop. doubling time 1.4–4.4y	42 (moderate)
Jack mackerel <i>Trachurus declivis</i>	25–40	16	3.9	0.36 @12°C	3–4	63,000 per batch/205 eggs per g	0.29	1.12	Medium, min. pop. doubling time 1.4–4.4y	50 (moderate—high)
Peruvian jack mackerel <i>T. murphyi</i>	45	16	3.5	0.12 @15°C	2–3	n.a. in Australia	0.1	0.42	Low, min. pop. doubling time 4.5–14y	67 (high–very high)
Blue mackerel Scomber australasicus	35 FL	7	4.2	0.41 @15°C	2–3	70,000 per batch/135 eggs per g	0.24	1.34	Medium, min. pop. doubling time 1.4–4.4y	43 (moderate)
Australian anchovy Engraulis australis	10 SL <sup>3</sup>	>2	3.0	0.82 @15°C	14	~15,600 per batch <sup>5</sup>	0.39 (1.3 <sup>6</sup> )	3.04	High, min. pop. doubling time <15 months	29 (low–moderate)

Source: Rogers et al. (unpublished), Appendix 4 and references therein, FishBase (Froese and Pauly 2014).1 Vulnerability from FishBase based on Cheung et al. (2005); 2 resilience from FishBase (Musick 1999): minimum population doubling time; 3 Yearsley et al. (1999); 4 Blackburn (1950); 5 Dimmlich et al. (2009); 6 Dimmlich and Ward (2006).

As the smallest species in this suite, Australian anchovies and sardines have the highest natural mortality, growth coefficients and relative fecundity of all small pelagic species. The other species fall into a slightly larger group (medium-size: about 30-40 cm) with similar attributes, apart from Peruvian jack mackerel which, curiously, has lower mortality, growth coefficients, resilience/productivity values and, consequently, higher vulnerability value. Whether the parameters used in the calculations of resilience/productivity and vulnerability for this species are representative of the Australian population is unknown. Peruvian jack mackerel doesn't appear to spawn in Australian waters but is abundant across the Pacific Ocean basin. Bulman *et al.* (2008) note that the species is taken only occasionally in Australian fisheries. It occurs in mixed schools with jack mackerel, and is not identified specifically in catch records. The panel considered that it was unlikely that incidental catches of this species in the SPF are significant.

SPF target species are all batch spawners, producing batches of eggs over a period of time. Relative fecundity, i.e. the numbers of eggs per gram (g) of body weight increases with body size, therefore the presence of older, larger fish increases potential reproductive capacity (Jennings *et al.* 2001, Garcia *et al.* 2013). These species all mature relatively quickly at within 2–4 years of age (Tm).

Resilience/productivity and vulnerability indices for SPF fishes and Australian anchovy were calculated in FishBase using Australian population parameters where possible (Table 6.1). The SPF species have medium resilience/productivity and vulnerability scores of 50 or less, except for Peruvian jack mackerel, for which the values for both attributes are similar to those of blue grenadier *Macruronus novaezelandiae* and gemfish *Rexea solandri* (low resilience for both and vulnerabilities of 66 and 65 respectively). Jack mackerel and jackass morwong *Nemadactylus macropterus* have the same vulnerability of 50 but morwong has a low resilience. Therefore, the SPF species are similarly or less vulnerable to fishing than other commercial species based on life history and ecological characteristics.

#### **Behaviour**

One of the areas of uncertainty that underpinned the first Final Declaration is related to the ability of the DCFA to stay on a school of small pelagic fish, implying an ability to detect, follow and capture the whole school. An examination of the schooling behaviour of small pelagic species is therefore warranted.

Schooling is common among fishes; about 80 per cent of all fishes school at some stage in their life (Freon and Misund 1999). One of the primary functions of schooling is to decrease an individual's chance of predation i.e. 'safety in numbers'. Ironically, it is this behaviour that increases the vulnerability of the species to detection and capture by fishing.

However, fish display surprising flexibility in their schooling behaviour and consequently their ability to avoid capture. For example, Norwegian herring schools demonstrated different and rapid responses to the approach of other schools, and small and large predators (including a vessel) (Pitcher *et al.* 1996). The herring responded to vessel approach in the same way as to an attack by a large predator; they dived to 150 m but this incurred an energetic cost.

The panel spoke with Mr J. Zeeberg, a researcher in the sardinella *Sardinella aurita* and *S. maderensis* fishery off Mauritania during the 2000s, who described the fishing strategy of the large Dutch mid-water trawl freezer vessels in that fishery. Sardinella form large shoals during the day and disperse at night. The trawlers use a 'spaghetti' search pattern to hunt schools of fish, often concentrating on temperature fronts where the fish are known to aggregate (Zeeberg *et al.* 2006). Occasionally, whole schools of up to 200 t were caught, but usually catches were 50–60 t and the whole school was not taken (Zeeberg *et al.* 2006, Mr J. Zeeberg pers. comm. 1 May 2014). In Australia, schooling behaviour of Australian sardines is variable, both spatially and temporally (Associate Professor T. Ward, unpublished data cited in Ward *et al.* (2010)). The early jack mackerel purse seine fishery off the east coast of Tasmania in the 1980s relied on surface schooling behaviour of the fish during the daytime to enable detection and capture (see Section 3.1.1). Schools occurred in spring and autumn off NSW and in summer and autumn off Tasmania probably as feeding aggregations in response to locally abundant krill swarms at the time (Williams and Pullen 1993). Entire schools were usually caught, ranging in size from 2 to 1850 t and most sets were during the day (Williams and Pullen 1993). During winter and spring, sub-surface schools increased. The composition of the schools was mostly jack mackerel in early summer, but became mixed with redbait, particularly in spring, and blue mackerel migrating from deeper water on shore, in late autumn. As discussed above, the surface schools disappeared in response to changed oceanographic conditions.

In southeastern Australia, fishing is targeted at summer feeding aggregations of blue mackerel, which begin to form in December when sea surface temperature (SST) is around 18°C to 22°C (Ward *et al.* 2001b). Blue mackerel migrates southwards as the EAC extends as far as southern Tasmania and retreat as the warm water retreats (Ward *et al.* 2001b), accounting for the increased occurrence in Tasmanian catches into autumn. At this time, blue mackerel is largely caught by the recreational and game fishers as bait for striped marlin *Tetrapturus audax* in NSW waters (Ward *et al.* 2001b).

Between 2003 and 2009, the SPF mid-water trawl fishery targeted redbait. The panel spoke with fishers and scientists about the schooling characteristics of redbait and the implications for fishing. Redbait typically aggregate into layers or form small (about 1 km) shoals during the night, which are patchily distributed and probably loosely connected. The time over which these schools or shoals hold together is also quite variable and they can vanish as quickly as they form. Dr J. Lyle noted that "over a period of 24 hours fish schools appear highly dynamic, scattering and reforming, they do not maintain formation" (Dr J. Lyle, IMAS pers. comm. 18 March 2013). Similarly (Seafish Tasmania Pty Ltd *in litt.* 16 October 2012) noted that "schools form, fragment and disperse within short timeframes, sometimes before there is even time to set the trawl".

#### Habitat association

The Rogers *et al.* (unpublished) review found that if an adverse effect of localised depletion on the stock was to occur, "a component of the fish population or meta-population must exhibit a degree of site fidelity to the fished area, and that some components (e.g. aggregations, size/age classes or sub-stocks) of the small pelagic fish populations exhibit separation from the broader stock over a particular time scale". Generally, species that would exhibit such site attachments are those that are strongly dependent on physical habitats for protection or food, such as reef-associated species, but could include species that have particular habitat requirements depending on life stages. Geographical features such as bays, headlands and straits may also contribute to the structuring of populations. This is particularly true in regard to Australian anchovy, which tend to be confined to embayments (Schwartzlose *et al.* 1999), and to some extent to Australian sardines, as in the Port Phillip Bay nursery grounds (Neira *et al.* 1999). Atlantic menhaden in Chesapeake Bay were suggested as potentially vulnerable to localised depletion due to populations being restricted to embayments. However, while site fidelity was exhibited by this species, there is no clear evidence that localised depletion occurs at a detectable and adverse level (Haddon 2009, Pikitch *et al.* 2012).

Pelagic species are highly mobile and more likely to be associated with prevailing oceanography in three-dimensional space, making the task of defining preferred habitat more difficult as the boundaries or range distributions will be highly fluid (Bulman et al. 2008). The oceanic or pelagic 'habitat' is complex and characterised by abiotic factors such as temperature, salinity, oxygen, light, current speed; and biotic factors such as prey, predators and fishes of similar functional role including conspecifics (Freon and Misund 1999). Barange et al. (2009) found that it was important to know the spatial extent and habitat characteristics of the species to fully understand the population dynamics. Rogers et al. (unpublished) found that small pelagic fishes are "responsive to oceanographic features, such as eddies, sea surface temperature and chlorophyll fronts that border upwelling systems, enhance food availability and determine the suitability of environmental conditions for growth, reproduction and recruitment". The scale at which oceanographic features occur can be from tens to hundreds of kilometres and may even define sub-structuring in populations. However, these features can serve to aggregate the fish, making them vulnerable to fishing, e.g. sardinella in North Africa (Zeeberg et al. 2006, Zeeberg et al. 2008). It is also the variability of oceanographic conditions and features that determine to a large degree the rise and fall of small pelagic species, with or without fishing (Lluch-Belda et al. 1989, Schwartzlose et al. 1999, Chavez et al. 2003, Cury and Shannon 2004, Lehodey et al. 2006, Tourre et al. 2007, Zeeberg et al. 2008) and, indeed, these were implicated in the collapses of the jack mackerel fishery off Tasmania in the 1970s and late 1980s (Harris et al. 1991, Harris et al. 1992).

Habitat can be defined at the population-scale in the sense of a global environment suitable for the whole stock or at a micro-habitat scale relevant to life-history stages of the species such as spawning or feeding (Freon and Misund 1999). It is the latter scale that is relevant to the potential for localised depletion to occur within a species. For example, juvenile SBT show a strong summer site fidelity to the GAB where the combination of SST and chlorophyll *a* is characteristic of their preferred habitat (Basson *et al.* 2012) and increases their susceptibility to capture. In the 1990s, 'fish favourable habitats' for all tuna species and jack mackerel were characterised by using combined logbook data on catch and satellite imagery (ocean temperature). This knowledge was used to assist fishers to locate schooling fish (Dr V. Lyne, CSIRO pers. comm. 4 July 2013).

Ovenden (unpublished), reviewed genetic studies on the SPF target species and supported Richardson's (1982) suggestion that overlapping, but genetically distinct, populations of jack mackerel probably occur as a result of spawning site fidelity. Maxwell (1979) proposed that jack mackerel migrated southward with the 17°C thermocline as the EAC extended, based on observations that jack mackerel schools surfaced when the SST was 17°C. Jordan *et al.* (1995), however, asserted that a resident population occurs in eastern Tasmania which might be supplemented by a small southerly migration. They thought resident schools surfaced as the thermocline advanced rather than a migrating school 'following' the thermocline. This hypothesis tends to support the original conclusion of distinct populations on the east coast of Tasmania but also highlights an association of jack mackerel with SST.

Whichever hypothesis is correct, jack mackerel off eastern Tasmania were found to move from shelf to deeper water to spawn during the summer probably to avoid the more variable surface conditions of the EAC (Jordan *et al.* 1995). This migration to deeper water, leaving the smaller non-spawning fish on the shelf, rendered them less susceptible to capture. A peak in landings indicated that adults returned to the shelf in autumn (Jordan *et al.* 1995). Coincidentally, 'deeper' jack mackerel took advantage of the 'bloom' of mesopelagic fish that occurs on the upper slope at this time which follow the primary productivity blooms in the early summer (Blaber and Bulman 1987, May and Blaber 1989). These observations again suggest an 'association' of jack mackerel with oceanographic conditions that are favourable to them when they are spawning or feeding and which would dictate their behaviour and movement, and consequently, their susceptibility to capture.

#### Mobility

Mobility was commonly mentioned in discussions with stakeholders and other experts as an important factor in determining how vulnerable SPF target species would be to localised depletion, or in other words, how long a localised depletion event (i.e. a removal by fishing) would persist and whether that length of time would impact their predators. Local and international fishers and scientists described the ephemeral nature of the fish schools and their ability to disappear from the sounder display. The ability of small pelagic fish to swim fast is an obvious advantage in avoiding capture; herring were measured to swim at 10 knots (Pitcher *et al.* 1996), and sardinella at 7 knots, easily outrunning the vessels towing at 5–6 knots (Mr J. Zeeberg pers. comm. 1 May 2014). However, their ability to evade capture also depends on their endurance, which is proportional to body length (Jennings *et al.* 2001). Peraltilla and Bertrand (2014) measured Peruvian anchovy schools swimming at an average *in situ* speed of 0.6 metres per second (m/s) (approximately 2.2 km per hour) but slower than the larger clupeids that they reviewed. They calculated that anchovy could travel a maximum distance of about 26 km (14 nautical miles (nm)) per day which corresponded to observations by fishermen of 22–33 km per day (12–18 nm). As discussed in the preceding section on habitat association, association of pelagic species with their favourable oceanographic habitats can only be achieved by a superior ability to swim.

Swimming speed and endurance is also important in evaluating how quickly a stock can redistribute to fill a void created by a fishing event and thus its ability to withstand depletion from fishing. Faster-swimming pelagic species would be expected to do this more quickly than slower-swimming demersal or site-associated species. Schools are highly mobile and constantly forming and reforming, therefore 'holes' are unlikely to remain in the same place in which they were formed for very long. The length of time of the depletion depends upon the species removed, but there are no specific studies on the SPF species.

## 6.5 Impacts of localised depletion on target species

Localised depletion of a target species has the potential to affect overall stock status, reproductive capacity and genetic diversity. Each of these is discussed below.

#### 6.5.1 Stock status

The impact of localised deletion of a target species on its stock status will depend in part on whether the stock as a whole is being managed sustainably. A stock that is in an overfished state, or for which catch/effort limits are not set sustainably, is clearly more susceptible to the impact of localised depletion events than well-managed stocks.

In the SPF, no target species is considered overfished or subject to overfishing. Only the western stock of redbait is considered uncertain, since there is no biomass estimate (Moore *et al.* 2013). Catch levels in the SPF are set in accordance with the SPF Harvest Strategy (Australian Fisheries Management Authority (AFMA) 2008) which was developed in line with the Commonwealth Harvest Strategy Policy (see Section 3.1.4) which requires that all Commonwealth-managed fisheries are managed to maximum economic yield (MEY) or 1.2 times the biomass at maximum sustainable yield ( $B_{MSY}$ ).  $B_{MEY}$  is not considered an appropriate reference point for species in the SPF because of the high inter-annual variability in the abundance of small pelagic fish species and their ecological importance as forage fish. The SPF Harvest Strategy is based on direct estimates of spawning stock biomass from daily egg production method (DEPM) surveys. Exploitation rates are limited to 20 per cent of spawning stock biomass (Ward *et al.* 2013a).

The panel considered that this approach is sufficiently precautionary to ensure the sustainability of the target species themselves. However, the panel acknowledges that many stakeholders remain concerned about the age and accuracy of the DEPM data used to estimate spawning biomass and set recommended biological catches (RBCs) under the SPF Harvest Strategy. The panel interviewed several experts on the DEPM (Dr F Neira, Marine Sciences Consulting; Assoc. Prof. T. Ward, South Australian Research and Development Institute; and Dr J Lyle, IMAS) in April 2013 and reviewed the re-analyses by IMAS (Hartmann 2012, Lyle *et al.* 2012) and the review of IMAS estimates by Dr N. Lo (retired from the United States National Marine Fisheries Service (NMFS), *in litt.* 11 February 2013). Two panel members attended a recent Technical Workshop and Stakeholder Forum on Small Pelagic Fisheries (Adelaide, 14–18 July 2014). The outcomes from that workshop will include a review of DEPM methods used in Australia and suggestions for improvement of those methods.

The panel was informed of egg surveys undertaken in the most recent spawning season that will allow updated assessments of stock biomass for jack mackerel and Australian sardine (East). The panel remains confident that, should these assessments show the need to revise RBCs for these species downwards, action will be taken in accordance with the SPF Harvest Strategy. As a result, the panel considered that concerns about the DEPM and RBC estimates are being dealt with effectively in parallel to its assessment and the panel saw no value in duplicating effort in that area.

#### 6.5.2 Change in size and age structure and reproductive capacity

Removal by fishing changes the size structure of the population, particularly if schools are of similar-sized fish, as is often the case in small pelagic species. Selectively taking the larger fish in the population, often based on economic considerations by the fishers, can reduce reproductive potential of the population as the older fish are bigger and fecundity is relative to size. To some extent, this reduction may be compensated by increases in fecundity such as that demonstrated by orange roughy *Hoplostethus atlanticus* when fecundity and the proportion of females spawning increased when the stock had been reduced to very low levels of spawning biomass (Pitman *et al.* 2013). The opposite trend, i.e. declining fecundity with increasing population density, was found in Gulf of Riga herring although recruitment was thought to be more variable (Raid *et al.* 2010).

Other density-dependent effects include earlier sexual maturation at smaller size. Jørgensen *et al.* (2007) detected widespread changes in maturity across decades of fisheries data that were thought "unlikely to be explained by environmental influences alone". Fishing that is selective with respect to size, maturity status, behaviour or morphology causes further evolutionary pressures (Jørgensen *et al.* 2007). Walters and Martell (2004) discussed size-selection as

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an inevitable result of fishing but noted that there is considerable variation in the way growth and maturity are linked. 'Age-linked' fish show declines in body size for age under selective fishing as in the case of Pacific salmon, whereas 'size-linked' fish tend to have increased growth rates and earlier maturation, affording them a selective advantage over the older, larger fish being fished. The difficulty in separating the genetic selection process from density-dependent and climate-change effects results in ambiguous conclusions about size-selective fishing (Walters and Martell 2004).

In the South Australian Sardine Fishery (SASF) in 2005, management was faced with the possibility that localised depletion may be occurring in Spencer Gulf with a total allowable commercial catch (TACC) of more than 50,000 t taken largely within around 3000 square kilometres (km<sup>2</sup>) and particularly from the grounds closest to Port Lincoln (Shanks 2006). While the evidence that suggested that localised depletion had occurred was based on low egg counts from surveys in 2005, there were mitigating factors that precluded a definitive conclusion. It was assumed that stocks of Australian sardines were mixing due to their 'highly motile nature' and therefore replenishing those caught in the fishery in Spencer Gulf (Shanks 2006). This challenged the conventional notion of localised depletion of geographically separated or limited mixing stocks. However, the fishery effort was also moving further from fishing grounds (as in the cases of serialised depletion of mackerels in the Java Sea and anchovy in the Humboldt Current off Peru in Box 6.1). Therefore, while there was no definite conclusion regarding whether localised depletion was occurring, management decided to adopt a precautionary approach and the TACCs were lowered and are now set at around 30,000 t. However, in the Spencer Gulf fishery, modal size has declined from approximately 15.0 cm fork length (FL) to 13.0 cm FL in 2012 (Ward *et al.* 2012a). This decline was thought to be partially due to lower growth rates, but fish older than three were declining while the proportion of immature fish was increasing, and a decreased egg density in 2011 DEPM surveys suggested that a concentration of fishing effort in Spencer Gulf was also contributing.

The most recent assessment of the SPF examined all length frequency data for jack mackerel collected from the beginning of the purse seine operations in the 1980s until 2010–11 when there was no fishery operating (Ward *et al.* 2014). The early purse seine catches (1984–91) were dominated by four to five year olds, but in 1991–92 and 2004–05 catches were dominated by three to four year olds, and in 2009–10 the two and three year olds dominated purse seine and midwater trawl catches. This might be evidence for overfishing but other factors such as recruitment variability and targeting were suspected as more likely, since catch and effort was low in the latter years (Ward *et al.* 2014). Data collected during the early fishery (Williams *et al.* 1986, Williams *et al.* 1987) indicated that the older fish were often absent from catches but it was thought that they moved to deeper water to spawn and were therefore unavailable to the fishery (Jordan *et al.* 1985). This hypothesis was supported by trawl surveys over the upper slope at around 400 m off Maria Island in the mid-1980s in which jack mackerel were the third most abundant species caught in mid-water trawls (May and Blaber 1989). As mentioned previously, these fish were feeding primarily on myctophids which were particularly dense around autumn (Blaber and Bulman 1987) and when the adult fish had probably finished spawning.

There have been no detectable changes in the age or size composition of redbait in recent years (Ward *et al.* 2014), suggesting that there were no impacts from fishing. There are too few data available for the Australian sardine in the Eastern Zone and blue mackerel to determine significant changes with confidence, but the low levels of effort and catch suggest little likelihood of recent fishing impacts on reproductive capacity (Ward *et al.* 2014).

## 6.5.3 Loss of genetic diversity

Localised depletion could potentially reduce genetic diversity if there was strong sub-structuring of the populations with the possible effects of reduced recruitment, reduced population size and an overall reduction in the genetic diversity of the resource (Ovenden unpublished). Two types of genetic changes resulting from fishing were considered by Walters and Martell (2004) as "particularly worrisome: erosion of spatial structure, and selection for changes in body size and maturity". Lindholm and Maxwell (1988) identified the potential risk to genetic diversity posed by the purse seine fishery for jack mackerel because of its ability to catch entire schools.

Ovenden (unpublished) reviewed the literature on genetic studies of SPF species in Australia, finding evidence for the existence of Wahlund effects in jack mackerel and Australian sardine. Wahlund effects indicate genetic sub-population structuring and thus are relevant to stock structure and management at a localised level. They occur when two or more genetically different populations are inadvertently sampled from the same sampling location. Normally, genetically

different populations do not co-occur, or they are distinguishable and are not co-sampled. The Wahlund effect occurs when there is a deficit of heterozygotes at the majority of loci and is extremely rare in pelagic fish populations. Pope *et al.* (in prep.) (cited in Ovenden (unpublished)) found that of published studies on 41 finfish species in Australia, only two (jack mackerel and damselfish *Acanthochromis polycanthus*) exhibit the Wahlund effect. Dixon *et al.* (1993) and Yardin *et al.* (1998) observed a deficit of heterozygotes for Australian sardine suggesting a Wahlund effect (Ovenden unpublished). The effect did not appear evident in species such as blue grenadier, orange roughy, jackass morwong, atherinid fish *Craterocephalus capreoli*, spikey oreo *Neocyttus rhomboidalis*, SBT and black marlin *Makaira indica*, all of which occur within the region of the SPF (Ovenden unpublished).

The presence of the Wahlund effect in jack mackerel and Australian sardine may, therefore, be associated with the presence of genetically distinct spawner groups (GDSG) plus the mixing of genetically distinct offspring, possibly during the feeding (i.e. non-breeding) phase. The Wahlund effect may have been observed because of the life-history stage of samples that were taken for genetic analyses. How genetically distinct populations are produced and maintained is unknown, but could include natal homing associated with spawning, schooling behaviour and post-mating reproductive barriers. Whatever the mechanism, it is highly likely that it operates between and within GDSGs, at and during spawning times and at spawning locations.

#### Summary: Potential impact of localised depletion arising from the DCFA on target SPF species

- SPF target species:
  - have a schooling behaviour that is dynamic and difficult to predict, although there are some diurnal patterns in schooling behaviour
  - are vulnerable to capture by way of their schooling behaviour and associations with oceanographic features such as eddies, and temperature and chlorophyll fronts
  - are proficient swimmers that can avoid capture to some extent and also redistribute relatively rapidly
  - are productive and fecund but subject to fluctuating environmental conditions to which they may respond dramatically
  - have some inherent characteristics that make them vulnerable to localised depletion, but have others that are likely to reduce the temporal and spatial extent of any such depletion and the level of adverse environmental impacts on predator species that might arise.
- Given the conservative exploitation rates in the SPF and that concerns about the basis for spawning stock biomass estimates are being addressed, the panel considered that any localised depletion of SPF target species that might arise from the DCFA was unlikely to affect the overall status of stocks of those species in the SPF.
- The ability of a vessel to stay on a school of fish and therefore take a greater proportion of that school, so as to increase the extent of localised depletion:
  - is dictated more by the behaviour of the school than by the particular characteristics of the mid-water trawl vessel
  - is not significantly affected by the freezing and processing capacity of the vessel specified in the DCFA.
- According to the panel's definition, localised depletion of jack mackerel inevitably occurred during the 1980s, at least temporarily, but there is also clear evidence for a non-fishing, i.e. environmental, cause for the changed behaviour of jack mackerel and its perceived absence. Despite active research in the fishery, there were no apparent indications of adverse environmental impacts directly resulting from the fishery on jack mackerel in the 1980s.
- The available genetic evidence for jack mackerel did not suggest that past, apparently high, levels of fishing had significantly affected reproductive capacity.
- There have been no significant changes in the age or size composition of redbait in recent years that might indicate a potential impact on reproductive capacity. There are too few data available for the Australian sardine in the Eastern Zone, or blue mackerel, to determine with confidence if there have been significant changes to date, but the low levels of effort and catch suggest little likelihood of fishing impacts on age, size structure or reproductive capacity.

• There is no evidence to suggest that localised depletion has caused any impacts on genetic diversity in the SPF stocks. Further research into stock structure would be required in order to inform management of the potential risks of localised depletion at the sub-population level and the appropriate spatial scale at which to manage effort and catch.

## 6.6 Ecological allocation to central place foragers

Hannesson *et al.* (2013) found that, for four small pelagic fish crashes, effects were felt on marine mammals and seabirds, but very little impact was seen on other commercial fish stocks, due to 'replacement' species taking on the support food role, or at least partially, for those predators. However, for birds, the effects are far more evident. In addition to the examples cited in Section 6.3, the carrying capacity of South African penguins *Spheniscus demersus* has declined by 80 to 90 per cent due to competition from the sardine fishery and fur seals (Crawford *et al.* 2007) and declining populations of Guanay cormorants *Phalacrocorax bougainvillii* and Peruvian boobies in the Humboldt Current have also been linked to fisheries (Bertrand *et al.* 2012). The general rule 'a third for the birds' was coined by Cury *et al.* (2011) who examined the effect of low trophic level species depletion on seabird populations. They modelled the empirical relationships between breeding success of 14 seabird species from nine sites in seven ecosystems, to their prey abundances. They concluded that, to maintain healthy top predator populations and ecosystem function, forage fish populations should be maintained at above one-third of the maximum long-term observed biomass (Cury *et al.* 2011).

Hannesson *et al.* (2013) suggested that trade-offs are necessary in order to support the world's growing food supply with supplements of fish meal and oil for agricultural use. Essington and Munch (2014) developed a method to assess these trade-offs in 27 ecosystems. Their findings were highly variable and they concluded that the limited ability to predict food web implications necessitated that a "precautionary risk-based approach be applied to decisions about acceptable biological removals of forage fish and biological targets used for their management" (Essington and Munch 2014).

The critical issue is to determine the level of removal of the prey species that, when added to the requirements of the overall ecosystem and taking into account natural variability, will not cause unacceptable adverse impacts to the ecosystem or components. As discussed in Chapter 4, ecological modelling of the southern Australia region, particularly by the spatially explicit Atlantis-SE model or Atlantis-SPF model (being applied in the current review of the SPF harvest strategy, Fisheries Research and Development Corporation (FRDC) project 2013/028), indicate that current exploitation rates under the SPF Harvest Strategy appear to provide an adequate 'ecological allocation' to the CPFs and other dependent predators, and that no adverse impacts are likely at that current level of allowable harvest. However, the models give results at a spatial scale that is less finely resolved than is required to identify adverse impacts on particular species of CPF such as fur seals, sea lions and birds. To avoid those impacts the ecological allocation needs to be within reach of the CPFs, both spatially and temporally.

The ability of predators to switch prey in times of reduced prey availability can mitigate the effects of depletion. This ability is inherent in predators of small pelagic species so as to be able to cope with the fluctuations of abundance of their prey that are caused by environmental variability, and which may be indistinguishable from the fluctuations caused by fishing. However, some predators, while being able to switch prey when necessary may be switching to sub-optimal diets that in the long term reduce breeding success or longevity.

It is also important to recall that, while there is a difference between localised depletion and overall stock depletion and range contraction, to some site-dependent species, such as land-based marine mammals and seabirds, the distinction is irrelevant. They may suffer the consequences of reduced availability of prey within their foraging ranges in either case.

The case of the decline of the western Alaskan stock of Steller sea lion *Eumetopias jubatus* (see box 6.2) demonstrates the complex interplay of ecological processes, environmental variability and anthropogenic pressures at work in an ecosystem, and the need to consider temporal and spatial scales as we have discussed previously. It provides an insight to the challenge of managing fisheries for the potential adverse effects on ecosystems. A vast amount of research conducted over the past decade has not reached a conclusion about the cause of the decline of the Steller sea lion stock. This serves to highlight not only the need to understand the role that prey fish or 'forage' fish play in ecosystems but, more importantly, that there can be several interacting factors that make effective management difficult to implement. Management measures for the Steller sea lion are further discussed in section 6.7.2.

#### Box 6.2 Steller sea lions in Alaska

The endangered western population of Steller sea lions in the Aleutian Islands and Bering Sea had declined by 90 per cent by 2000. Prior to 1990, the cause for the decline was blamed on commercial harvest of the sea lion and fatal interactions with the state commercial fisheries including juvenile entanglement in fishing gear and illegal shooting. However, following the cessation of direct harvesting, the western population failed to recover, unlike the eastern population.

"Many have speculated on reasons for the decline in the 1980s and 1990s, including a climate regime change in the late 1970s that may have altered habitat conditions and prey abundance and diversity, increased predation, intentional and non-intentional human-caused mortalities, and fishery effects. It is generally agreed that the primary factor or factors responsible for the steep decline in the 1980s will never be identified with any assurance. Likely it is a combination of multiple factors (National Research Council (NRC) 2003). In this last decade, the available information on birth and death rates indicates that adult and juvenile survival rates are similar to those pre-decline, but that natality with some exceptions has declined on the order of 30 per cent relative to the pre-decline era. Our understanding about changes in these vital rates is limited as the number of sub-regions properly studied in the western DPS [distinct population segment] is limited to three at best." (NMFS 2010)

The difficulty in explaining the decline of the western population of sea lions is partly due to a high degree of spatial and temporal variability in the population and environmental variables thought to be responsible (Wolf *et al.* 2006). The fact that the sea lions show a degree of site fidelity was a clue to looking more closely at finer-scale analyses. By using data resolved to a finer-scale and a multiple (10) hypothesis approach, Wolf *et al.* (2006) demonstrated that there were possibly several mechanisms at play. Two strong effects were that food availability affected the fecundity of the animals and that, as pollock in the diet increased, pup recruitment declined. Whether this was from too much pollock or not enough other fish was unknown. To a lesser degree, harbour seal density was correlated with sea lion 'non-pup' survival, i.e. when harbour seals were less abundant, orcas ate more sea lion pups.

In 2010, the NMFS issued an Endangered Species Act (USA) (section 7) biological opinion on the authorisation of the groundfish fisheries of the Bering Sea and Aleutian Islands, Gulf of Alaska and the State of Alaska. The biological opinion found that NMFS could not ensure that the groundfish fisheries were not likely to jeopardise the western stock of Steller sea lions or adversely modify or destroy critical habitat. Localised depletion of Atka mackerel *Pleurogrammus monopterygius*, pollock and Pacific cod *Gadus macrocephalus* were suggested as impacting sea lions' growth and productivity and reproduction. Highly controversial new restrictions were implemented to protect the species and critical habitat, particularly in the Aleutian Islands, which were not popular and resulted in legal challenges. NMFS was required to produce a cooperative Environmental Impact Statement and a range of alternative spatial closures. Several scientific reviews were also conducted on the biological opinion, all of which were critical. As a result, NMFS identified areas that warranted further analysis or modification. The most recent 2014 biological opinion has been developed by NMFS after reviewing the Environmental Impact Statement, previous biological opinions and relevant management plans, the Steller Sea Lion Recovery Plan and the best available data.

The management actions currently proposed are a suite of measures to control the location, gear type, timing, and harvest amount for Atka mackerel, pollock, and Pacific cod fishing in the Aleutian Islands to avoid jeopardising the western population of Steller sea lions or adversely modifying their critical habitat; and to minimise, as far as possible, economic impacts to the fisheries. Further research on fish abundance and distribution, and movement of Atka mackerel was also recommended to understand potential impacts of commercial fisheries on Steller sea lion prey species, particularly the potential for fisheries to cause localised depletion of sea lion prey and the efficacy of trawl-exclusion zones.

## 6.7 Impacts on central place foragers

## 6.7.1 Potential nature and extent of adverse impacts

Because central-place foraging predators (seabirds and pinnipeds) raise offspring on land, the availability of key prey resources near their breeding colonies at key times (e.g. incubation and chick rearing in seabirds, lactation in pinnipeds) is critical to their reproductive success and the longer-term sustainability and maintenance of breeding populations. This dependency on near-colony prey resources at certain locations and times increases the vulnerability of these species to localised depletion of prey in their key foraging areas.

Central-place foraging marine predators are highly responsive to changes in prey availability, which have been shown to impact their foraging behaviour, reproductive performance and survival (Croxall et al. 1988, Furness and Tasker 2000, Rindorf et al. 2000, Boyd and Murray 2001, Boyd et al. 2006, Croxall 2006, Daunt et al. 2006, Hamer et al. 2006, Furness 2007, Einoder 2009). Some impacts can be short-term (within a breeding season impacting chick/pup growth rates, survival, fledging/weaning success), or longer-term (broader demographic impacts on survival, recruitment, fecundity, age-structure, population growth rates and size). Many studies, particularly on seabirds, have shown that foraging and breeding success parameters can reliably predict and/or track changes in stock abundance, distribution and recruitment of commercially targeted species (Anderson and Gress 1984, Berruti and Colclough 1987, Montevecchi et al. 1987, Monaghan et al. 1989, Cairns 1992, Hatch and Sanger 1992, Bertram and Kaiser 1993, Montevecchi 1993, Croxall et al. 1999, Furness and Tasker 2000, Velarde et al. 2004, Cury and Christenson 2005, Furness 2007). In most of these studies, the actual causes of variability in the availability of commercially targeted fish stocks that impact predator foraging and reproductive performance are uncertain, however, some have been directly attributed to overfishing (Furness and Tasker 2000, Lewis et al. 2001, Bertrand et al. 2012). With the exception of the study by Bertrand et al. (2012), studies typically focus on attributing changes in predator performance to changes in prey availability, not whether the reduced prey availability has occurred as a consequence of overall stock depletion or localised depletion. For CPFs, such distinctions are largely semantic, as any reduction in prey availability within their restricted foraging ranges could lead to adverse impacts. For these reasons the panel considered that any case study where reduction in prey availability has been shown to contribute to impact on CPF species provided a valid example of the possible nature and extent of adverse impacts that could result from localised depletion.

The nature and extent of impact on CPFs of prey depletions within their foraging ranges will depend on the spatial and temporal scale of depletion (Reid *et al.* 2005, Croxall 2006). Short-term prey depletions on the scale of days may reduce foraging efficiency and increase the energetic costs of foraging due to reduced prey densities and longer search periods. This could lead to longer foraging trips and/or reduced meals size/milk transfer and rates of provisioning to offspring (chicks/pups). If depletions persist they will result in reduced chick/pup growth rates at the scale of weeks, and result in lower fledging/weaning mass and reduced chick/pup survival and adult-breeding success at the scale of months (depending on age at fledging /weaning). Longer-term depletions over the scale of years and decades can impact major demographic factors such as survival, recruitment and reproductive rates that drive population age structure, growth rates and ultimate size.

#### Summary: potential impact of localised depletion on CPF species

- The dependency on near-colony prey resources at certain locations and times increases the vulnerability of CPF species to localised depletion of prey in their key foraging areas.
- Although CPF species have been shown to be highly responsive to changes in prey availability within their key foraging areas, very few studies have linked reduced foraging and reproductive performance to the impacts of fishing, and even fewer to localised depletion.
- There may be no biological distinction between the nature and extent of adverse impacts on CPF species from any source of fishing induced prey depletion (at the stock or local level) within their restricted foraging range, although, by their nature, adverse environmental impacts caused by localised depletion may be shorter in duration (days to months) and less persistent than those caused by stock depletions.

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• The nature and extent of impact will depend on the spatial and temporal scale of the depletion. Short-term impacts may reduce foraging efficiency resulting in longer foraging trips and/or reduced rates of provisioning to offspring. If these persist they can result in reduced offspring growth rates, fledging/weaning mass and reduced survival, and reduced adult breeding success. Longer-term impacts can affect major demographic factors such as survival, recruitment and reproductive rates that drive population age structure, growth rates and, ultimately, population size.

## 6.7.2 Managing impacts of localised depletion on CPF species

The panel is aware of five main case studies where the potential impacts of localised depletion caused by fishing on CPF species are managed at some level. These are summarised below.

#### Peruvian anchovy and Peruvian boobies

The Humboldt Current System (HCS) off the coast of Peru hosts one of the largest guano-producing seabird populations in the world that includes the Peruvian booby, Guanay cormorant and Peruvian pelican *Pelecanus thagus*, which is underpinned by the largest, small pelagic fishery for Peruvian anchovy (Bertrand *et al.* 2012). The HCS is subject to high environmental variability, including El Nino (Chavez *et al.* 2008). Abundance of these seabirds varied between 3 and 8 million individuals between the early 1900s and 1940s to up to 16–28 million in the 1950s following protection of nesting areas in the 1940s (Bertrand *et al.* 2012). Industrial fishing for anchovy began in the late 1950s and grew rapidly, and by the early 1970s the stock had collapsed in response to overfishing, environmental conditions less favourable to anchovy and a major El Nino event (Bertrand *et al.* 2004). These events also lead to major collapses in seabird populations. Since then, both anchovy and seabird populations have recovered, although seabird numbers generally oscillate at historically lower levels (0.4 to 4 million, Bertrand *et al.* 2012).

Since the early 1990s, the anchovy fishery has been relatively stable with annual catch levels around 6 million tonnes per year. As the fishing season overlaps with the seabird-breeding season, concentration of fishing effort may impact on prey availability to seabirds during this critical period. Bertrand *et al.* (2012) simultaneously tracked fishing activity (all vessels fitted with a vessel monitoring system) and seabird foraging behaviour (birds fitted with GPS and dive logger tags) from the opening of the fishing season in 2007, to investigate if the foraging behaviour of Peruvian boobies was impacted by the distribution and intensity of fishing within their core foraging areas.

The study found that as the fishing season progressed, both the range of the daily trips and distances of the dives by birds from the colony increased, and were significantly related to concomitant fishing activity. The increase in foraging effort was significantly related to increasing removal of anchovy by the fishery, which was at more than 100 times greater than the daily anchovy requirements of the seabird colonies. Bertrand *et al.* (2012) concluded that the boobies foraged further as a consequence of localised depletion created by the intensive fishing within their core foraging areas, and that foraging efficiency of central placed foraging seabirds may be impacted by not only the global quantity, but also the temporal and spatial distribution of fishery removals. Bertrand *et al.* (2012) estimated that the fishery took around 1.1 million tonnes of anchovy in the study area, around half of which was taken during the tracking experiment. This equated to removal of around 30 per cent of the available anchovy biomass during the tracking study and 63 per cent during the entire fishing season.

Two key management changes in the Peruvian anchovy fishery have been introduced since the study by Bertrand *et al.* (2012), that may reduce some of the potential impacts of localised depletion on dependent seabird populations. Firstly, the fishery changed from open access to individual quota management in 2009, ending the competitive race for fish and, as a consequence, the fishing season is much more extended (e.g. from 48 days in 2007 to 189 days in 2009). Although the total quantity of anchovy catch remains similar between years, extending the fishing season has reduced the mean daily removals of fish from around 110,000 t per day in 2007 to around 29,000 t per day in 2009 (Bertrand *et al.* 2012). Because of the high mobility of anchovy, the probability of locally intense depletions is considered lower since the introduction of individual quotas (Bertrand *et al.* 2012). Secondly, marine reserves excluding the anchovy fishery out to 3.7 km from key seabird-breeding sites (22 islands and 11 headlands) were introduced in 2010, although Bertrand *et al.* (2012) suggest, based on their data, that these areas are not sufficient to sustain the foraging of seabirds during the fishing season.

#### North Sea sandeels and seabirds

Sandeels Ammodytes marinus are small energetically valuable bony fish that burrow into the seabed and form aggregations in the water column where they are accessible to, and form an important prey source for, many marine predators, including seabirds, seals and cetaceans (Camphuysen et al. 2006, Rogers et al. unpublished). The sandeel fishery began in the early 1970s and peaked at around 800,000 t per year in the late 1970s. In the past decade, catches have averaged around 425,000 t per year (Pikitch et al. 2012, Rogers et al. unpublished). The effects of the severe collapse in sandeel stocks on some predator species have been reported and recognised (Bailey et al. 1991), but the relationship between sandeel densities and predator response are not well understood, and the degree to which seabird data are a proxy for fish abundance varies among species and needs to be interpreted with caution (Furness and Camphuysen 1997, Camphuysen et al. 2006). For example, where some seabird species fail to reproduce when sandeel stocks are low (Monaghan 1992), others appear to be able to adjust their foraging and switch to alternative prey (Martin 1989). A number of studies have examined the potential impacts of the sandeel fishery on seabirds; these generally assume that the availability of sandeels is critical to the breeding success of seabirds and that fishing intensity can reduce their availability. The key seabird species include black-legged kittiwake Rissa tridactyla, common guillemot Uria aalga, northern gannets Morus bassanus, Arctic terns Sterna paradisaea, Atlantic puffin Fratercula artica, razorbill Alca torda and European shaq Phalacrocorax aristotelis. Rindorf et al. (2000) showed that breeding success in seabirds was significantly reduced when sandeel availability to the fishery in June was low, and that the timing of the peak in sandeel availability affected reproductive success (lower when the peak occurred early). Seabird mortalities have also been related to low prey availability and competition with the fishery, and reduced reproductive success has been shown to correlate positively with sandeel abundance in Arctic terns and black-legged kittiwake (Monaghan et al. 1989, Furness and Tasker 2000, Rindorf et al. 2000, Furness 2002).

A key factor of sandeel ecology is their dependence on patchily distributed sandy substrates that can create the potential for low dispersal in juvenile fish and increase their potential risk to localised depletion (Pikitch et al. 2012). Furthermore, because the fishing season coincides with the main seabird-breeding season, there was considerable concern over the potential impacts of the fishery on seabird populations at this critical time. In response to scientific advice provided by the International Council for the Exploration of the Sea (ICES) Study Group on Effects of Sandeel Fishing on the dependency of seabirds on sandeel abundance, public pressure following a seabird mortality event, and in response to a precautionary ecological indicator (breeding success of kittiwakes falling below 0.5 chicks per pair over three consecutive breeding seasons), a near-shore area from eastern Scotland to north-east England was closed to the sandeel fishery (a spatial closure named the 'sandeel box') in 2000 (Frid et al. 2005). The fishery cannot reopen until breeding success exceeds 0.7 for three consecutive years (Frid et al. 2005). Hence, management of the potential impacts of localised depletion caused by this fishery is based on an ecosystem objective (seabird population health), is precautionary (the link is not yet proven), and uses kittiwake breeding success as an ecological performance indicator (EPI) of the ecosystem effects of fishing (Frid et al. 2005) (essentially an EPI trigger and fishery closure system). Daunt et al. (2008) concluded that the spatial closure can have benefits to those top predators sensitive to changes in the availability of target species, but noted that it was difficult to attribute the entire response to the spatial closure, as environmental variability that led to strong sandeel recruitment may have also been significant.

The latest advice from ICES suggests that although uncertainties still exist regarding the precise drivers of seabirdbreeding performance in the North Sea and the possible role of climatic and environmental change, concerns regarding the risks to seabird breeding success from sandeel fisheries remain, and without further management control, sandeel aggregations targeted by breeding seabirds could be subject to significant depletion. There is also much debate regarding the criteria by which the spatial closure might be re-opened (ICES 2014).

#### Benguela anchovy/sardine and African penguins

A major pelagic fishery targeting sardine *Sardinops sagax* and anchovy *Engraulis encrasicolus* has operated in the Benguela and Agulhas current systems off South Africa since the 1940s (Coetzee *et al.* 2008). They are also a key prey species of African penguin populations off South Africa and Namibia making up most (approximately 82 per cent) of their diet (Pikitch *et al.* 2012). The species appears highly vulnerable to changes in the spatial distribution and abundance of their prey, increasing during a period of relatively high fish abundance in 2000–2004, and declining since then as fish stocks have declined and shifted eastward (Crawford *et al.* 2006a, de Moor *et al.* 2011). Reduction in food availability

is thought to be the main cause of higher adult mortality and reduced breeding success. The recent decline in African penguin populations resulted in the upgrading of their conservation status to 'endangered' by the International Union for Conservation of Nature and Natural Resources (BirdLife International 2013).

As a consequence there has been increasing pressure to manage the South African purse seine fishery to ensure adequate escapement of anchovy and sardine to avoid excessive negative impacts on the breeding success of vulnerable predators such as the African penguins, by setting some threshold on stock abundance below which no catch can be taken (Crawford *et al.* 2006b, Cunningham and Butterworth 2006). To this end, the Pelagic Scientific Working Group (PSWG) of the Department of Agriculture, Forestry and Fisheries (South Africa) was tasked to evaluate if the available evidence suggested that fishing in the vicinity of penguin-breeding colonies negatively impacted their reproductive success. The working group examined data from two major breeding colonies on the west coast, Robben and Dassen islands, for which time series of indices of reproductive success were available, but results were not clear (Butterworth *et al.* 2011). The PSWG considered commencing a programme of experimental closures around penguin-breeding colonies to better estimate these indirect impacts, however, power analyses suggested that such an experiment might take up to two decades to provide reliable results because of the large variances in the relationship between the impact on reproductive success and the extent of fish catches (Brandao and Butterworth 2007 cited in Butterworth *et al.* 2011). This prompted a feasibility study for two pairs of island colonies (Robben/Dassen and St Croix/Bird with pelagic fishing suspended around one of each pair—20 km radius) for indices related to reproductive success.

Pichegru *et al.* (2010) compared the foraging effort of breeding African penguins at St Croix Island and Bird Island and found that the foraging effort of the St Croix Island (20 km fishing closure) penguins decreased by 30 per cent within three months of the introduction of the fishing closure while those at Bird Island (50 km away, opened to fishing), increased their foraging effort during the same period. In addition, following the closure at St Croix Island, Pichegru *et al.* (2010) noted that most of the penguins shifted their feeding effort inside the closed area. Pichegru *et al.* (2010) claimed their study reflected the immediate benefits of the introduction of the fishing effort was very low around St Croix Island in 2008 (before the closure) and that the results may simply reflect natural variability in prey abundances rather than impacts from the fishery. In contrast, penguin abundance has remained stable at Robben Island (open to fishing), but declined at Dassen Island (closed to fishing) during 2008 and 2009 (Coetzee 2010). Recent research by Robinson (2013) who examined relationships between penguin demographic parameters at these colonies and extractions of forage fish, taking account of fish abundance through biomass estimates from, have also proved inconclusive.

Fishery closures were introduced as a precautionary measure which, in conjunction with ongoing monitoring of penguin demographic parameters, provide a means to assess, over time, whether or not such closures benefit penguins (Coetzee 2010). However, results to date highlight the challenges in studying the indirect effects of fishing on dependent predator populations (Pikitch *et al.* 2012), and reinforce earlier assessments that such relationships may take decades to provide reliable results (Brandao and Butterworth 2007 cited in Butterworth *et al.* 2011). Attempts are being made to incorporate functional relationships between predators (namely penguins) and prey into the operating models for sardine and anchovy, augmented by population dynamics model(s) for the predator(s) of concern (Patterson *et al.* unpublished).

#### Alaskan fisheries and Steller sea lions

Steller sea lions (SSL) in the northern Pacific are the largest otariid pinniped. Key prey species in their diet include walleye pollock *Gadus chalcogrammus*, Pacific cod, and Atka mackerel which are also targeted by some of the world's largest fisheries. Following large declines, western stocks of SSL were listed as 'endangered' under the *US Endangered Species Act* in 1997, with the eastern stock listed as 'threatened' but recently de-listed.

Multiple hypotheses have been developed to explain the rapid decline in the western SSL stocks, many of which are still being robustly debated (NRC 2003, Wolf *et al.* 2006, Wolf and Mangel 2008, Boyd 2010). In fact, 10 hypotheses have been detailed, which can generally be categorised into four groups, including: food limitation; 'junk-food'; fishery-related mortality and predation-mortality hypotheses (Wolf *et al.* 2006, Wolf and Mangel 2008). The recent analyses suggest that food, both the quantity and quality of it, are likely to have been key factors in SSL decline (Wolf *et al.* 2006, Wolf and Mangel 2008). This is consistent with the major expansion of fishing roughly coinciding with the period of the SSL decline, and the considerable overlap in prey species and size classes of fish that are utilised by SSL and fisheries (Hennen 2006).

Fisheries' activities could plausibly affect SSL populations by changing fish species composition, distribution and/or abundance in a way that decreases SSL foraging efficiency (Hennen 2006). Both broad-scale stock depletions reducing the overall biomass of fish, and the uneven removal of fish that can lead to localised depletions, have been considered as contributing to the decline in SSL populations (NRC 2003). There is evidence that localised depletions of Atka mackerel has occurred as a result of fishing intensity in certain areas along the Aleutian Islands and in the Gulf of Alaska. This includes evidence for seasonal, localised depletion by trawl fisheries in eight areas between 1992 and 1995; a persistent depletion in the Gulf of Alaska between 1993 and 1994; and depletions at some sites in 1996 and 1997 (Lowe and Fritz 1997, Fritz 1999, NRC 2003). There is also evidence of localised depletion of walleye pollock in the eastern Bering Sea. Battaile and Quinn II (2006) used data from 1995–1999, stratified by small areas, short seasons and years. They identified a number of areas where localised depletion had occurred and noted that cumulative depletion over a season was inversely related to estimated initial biomass, total catch, and total effort, indicating that depletion is detected more easily in areas of low abundance and consequently lower catch and effort (Battaile and Quinn II 2006). Based on their findings, pollock may repopulate exploited areas in a relatively short time period (weeks).

A range of SSL protection measures were introduced between the 1990s and 2000s to mitigate against the potential indirect effects of fishing. These focused less on the overall rates of harvest and more on the temporal and spatial apportionment of catches so as to mitigate against the potential for localised depletion effects from the Alaskan groundfish fisheries (NRC 2003). These included fishing closures at specific times and locations to protect near-shore areas considered to be critical foraging areas. These 'critical habitat zones' consist of a 20 nm (37 km) buffer around all major haul-outs and breeding colonies as well as three large offshore foraging zones (Figure 6.1). Additional 3 nm (5.5 km) no-entry zones have been enacted within which no ground fishing or transit of vessels is allowed. The intent of the closures is to disperse fishing effort temporally and spatially in this region.

Have spatial closures been successful in mitigating the effects of localised depletion on SSL? As closures were introduced around all major breeding colonies in the western SSL stock range, a comparison between 'treatment' vs 'control' is not possible, and precludes a conclusive cause-and-effect relationship between fishing and the SSL population trend to be determined (Hennen 2006). Hennen (2006) showed a positive correlation between several metrics of historical fishing activity and SSL population decline. However, the relationship was less consistent following the introduction of management measures in 1991, supporting the hypothesis that management measures around some of the rookeries have been effective in moderating the localised effects of fishing activity on SSL. These results do not preclude additional factors having contributed to the stabilisation and in some cases increases in the populations; but population modelling analyses suggest that management actions taken since 1990 have probably been effective (Boyd 2010).



Figure 6.1 Designated critical habitat zones and fishery exclusion zones around Steller sea lion breeding (rookeries) and haul-out sites in Alaska. Source: National Oceanic and Atmospheric Administration, NMFS Alaska Regional Office (2014), (http://alaskafisheries.noaa.gov/protectedresources/stellers/maps/criticalhabitat\_map.pdf)

#### Antarctic krill and key CPF species

Antarctic krill *Euphausia superba* are a critical component of Antarctic and Southern Ocean food webs, supporting populations of baleen whales, seals, fishes, birds and cephalopods, which are all significant predators of krill. The krill fishery is managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR).

A fishery for Antarctic krill has been operating for more than three decades, and has been characterised as one of the world's largest underexploited fisheries (Nicol *et al.* 2012). Catches peaked in the 1980s at more than 500,000 t annually. Since the early 1990s the catches have been between 100,000 t and 200,000 t with further fishery development being constrained by the expense of fishing in the Southern Ocean and also a limited market for krill products. Both of these issues may be set to change, with increases in catches being perceived as likely (Nicol *et al.* 2012). In the Scotia Sea, where the bulk of the fishing occurs, catches are limited by a trigger level of 620,000 t until a procedure for dividing the precautionary total limit for the region of 5.61 million t amongst 15 selected small-scale management units (SSMUs) can be devised (Constable and Nicol 2002, CCAMLR 2012) (Figure 6.2). The trigger level was based on concerns that a regional limit is not sufficient to prevent spatially localised, indirect impacts on krill predators (Constable 2011). The intent of these SSMUs is to minimise indirect impacts of the krill fishery on dependent predators (Hewitt *et al.* 2004), and especially

address concerns about localised depletion (Pikitch *et al.* 2012). CCAMLR is yet to formalise how these areas are to be managed and is developing a set of candidate decision rules and testing around these (CCAMLR 2011). SSMUs are designed to facilitate spatial management options that would operate at finer spatial scales (Plagányi and Butterworth 2012).



Figure 6.2 CCAMLR small-scale management units in the Antarctic Peninsula and South Georgia region. Source: Hewitt *et al.* (2004), with permission from *CCAMLR Science* 

#### Summary: localised depletion on CPF species

- Based on the findings of many studies, and in the opinion of the panel, there is a potential for localised depletion of target species by the DCFA to adversely impact their predators. The most susceptible to impact would include CPF species, especially those with restricted foraging ranges while raising offspring and where species targeted by the SPF constitute a significant portion of their diet. Concentrated fishing activity at locations and times when CPFs are most susceptible to the impacts of prey depletion could reduce foraging success and lead to lower reproductive outputs and survival. If persistent, such impacts could lead to declines in populations.
- The panel is aware of five case studies where the potential impacts of localised depletion caused by fishing on CPF species are actively managed at some level. These are:
  - Peruvian anchovy and Peruvian boobies
  - North Sea sandeels and seabirds
  - Benguela anchovy /sardine and African penguins
  - Atka mackerel and Steller sea lions Alaska
  - Antarctic krill (CCAMLR fisheries).
- In only one case study (Peruvian boobies) is there compelling evidence for localised depletion. In three case studies (North Sea, Benguela, Alaska) where impacts on CPF predators have been identified (declines in population size and reproductive success), spatial closures have been introduced as a precautionary measure to mitigate potential adverse impacts of localised depletion, even though the causes of those impacts are uncertain. In one case study (the Antarctic krill fishery), spatial closures to protect CPF predators from indirect fishing impacts are only in development.

## 6.7.3 Key CPF species and areas in the SPF

The SPF region contains some of the largest populations of CPF predators in coastal Australian waters, including all of its fur seal populations (about 200,000 animals) and almost all of its Australian sea lion population (about 13,000 animals) (see Section 5.2), and numerous populations of seabirds including Australia's most abundant and biomass seabird, the short-tailed shearwater *Ardenna tenuirostris* (around 23 million) (Patterson *et al.* unpublished).

Dietary information on a range of marine predators, including CPFs, highlighting the importance of SPF species is summarised in Table 4.2. Based on available data summarised in this table, the subset of protected species of CPF seals and seabirds that occur within the SPF area and for which SPF target species occur in significant proportions in the diet (more than 10 per cent at some stage) include:

- Australian fur seal Arctocephalus pusillus doriferus
- New Zealand fur seal Arctocephalus forsteri
- Australasian gannet Morus serrator
- short-tailed shearwater Ardenna tenuirostris
- little penguin Eudyptula minor
- crested tern Thalasseus bergii
- shy albatross Thalassarche cauta.

Little terns are considered highly coastal and unlikely to forage extensively within the SPF area. Other potential species for which there is limited information on diet within the SPF area and which may rely on SPF targeted species during their breeding seasons include the flesh-footed shearwater *Puffinus carneipes* and wedge-tailed shearwater *Puffinus pacificus* (Gould *et al.* 1997, Bond and Lavers 2014).

With respect to areas within the SPF that constitute critical foraging habitat for key CPF species, there is a spectrum of data available across species. For pinnipeds, there have been broad global analyses of foraging distribution that use very simple foraging metrics to identify key regions at large spatial scales (e.g. Figure 5.4), and one instance where a very detailed regional model of foraging distribution has been developed for the Australian sea lion (Figure 5.5). As detailed in Chapter 5, most of the Australian and New Zealand fur seal populations reside in southeastern Australia, with the former most abundant in Bass Strait and the latter in South Australia (SA) (Figure 6.3). The panel is aware that extensive tracking data exists for both Australian and New Zealand fur seals (mostly from Bass Strait and SA, respectively) that could be used to identify key foraging areas. Most critical are those areas used by lactating females while raising dependent pups located onshore. For both species, pups are raised over a 10 to 11 month period between November and October. Although Australian fur seal females forage in shelf waters year round, New Zealand fur seals (at least in SA), partition their foraging by feeding in shelf waters between December and May, then transitioning to oceanic waters until the commencement of the next breeding season. The distance from breeding colonies that female Australian and New Zealand fur seals forage varies from colony to colony, often relative to the distance to key oceanographic features, but can also vary throughout lactation and in response to the distribution and availability of prey.

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Figure 6.3 Distribution of breeding colonies of six key CPF predators that occur in the SPF: a) Australian fur seal, b) New Zealand fur seal, c) short-tailed shearwater, d) little penguin, e) Australasian gannet, and f) shy albatross. Symbols are scaled to the size of the populations. The 200 m bathymetry isobath is indicated. Data for crested terns were not available for presentation. Source: S. Goldsworthy, South Australian Research and Development Institute (SARDI) unpublished.

Thirty-two CPF seabird species were identified as occurring within the SPF area (i.e. those CPF seabirds that breed somewhere within the SPF area). A CPF seabird density plot provides some measure of the distribution of CPF seabird species throughout the SPF, and highlights Lord Howe Island, Bass Strait and Tasmania, and coastal regions of NSW, SA and Western Australia (WA) (centred around islands with seabird populations) as key areas (Figure 6.4). However, Figure 6.4 does not accurately represent the at-sea distribution of CPF seabirds, nor does it identify the breeding sites for all species. For those key SPF seabirds identified above, both the number of breeding sites and the size of populations are concentrated in southeastern Australia (Figure 6.4). This is exemplified by the most abundant Australian seabird, the short-tailed shearwater (around 23 million, Patterson *et al.* unpublished)[Figure 6.4]. Also, most Australasian gannet colonies and all shy albatross colonies are located in Bass Strait and Tasmania (Figure 6.4). Little penguins breed across southern Australia, with the bulk of the population centred in Bass Strait (Figure 6.4). At least some satellite telemetry data exist for each species in parts of their range, but none of the datasets are comprehensive and cover all stages of the breeding period.



Figure 6.4 CPF seabird species in relation to the total area of waters fished in the SPF using mid-water trawl during 2000–2013. Source: Map produced by the Environmental Resources Information Network (ERIN), Department of the Environment using unpublished AFMA data.

The most comprehensive regional assessment and estimate of CPF species consumption and foraging distribution comes from research undertaken in SA by Goldsworthy *et al.* (2011), as part of a study into ecosystem-based management of the SASF. They undertook extensive satellite telemetry studies on five key CPF species, including the New Zealand fur seal, Australian sea lion, little penguin, short-tailed shearwater and crested tern. For each species, based on a subset of animals from representative sites, generic foraging models (statistical models of data distributions based on distance and depth) were developed and then applied to all known breeding sites, and using population data and consumption models, estimated the spatial distribution of foraging and consumption effort off SA (Goldsworthy *et al.* 2011) (Figure 6.5). Species foraging models were also combined to provide an overall estimate of the distribution of consumption effort of prey species by these CPF predators across shelf waters (Figure 6.6). Although such spatial models highlight regions of critical importance to CPF, they were not developed to assist in spatial management of the SASF or to manage the potential impacts of localised depletion. These models were global models in the sense that they pooled all the foraging effort of animals throughout the year, and did not just focus on critical periods (e.g. lactating females raising pups/adult seabirds raising chicks).



Figure 6.5 Raw satellite telemetry data (left column) that was used to model the spatial distribution of foraging effort across all breeding sites over shelf waters of SA, drawn as heat plots (right column). Species are New Zealand fur seal (a, b), Australian sea lion (c, d), short-tailed shearwater (e, f), little penguin (g, h) and crested tern (i, j). Source: S. Goldsworthy, SARDI unpublished; redrawn from data from Goldsworthy *et al.* (2011)

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Figure 6.6 Combined model of the spatial distribution of foraging effort for five CPF predators over shelf waters off SA, drawn as heat plots (New Zealand fur seal, Australian sea lion, short-tailed shearwater, little penguin and crested tern). Source: S. Goldsworthy, SARDI unpublished; redrawn from data from Goldsworthy *et al.* (2011)

#### Summary: key central place foragers in the SPF

- CPF predators that forage within the SPF and for which SPF target species make a significant (more than 10 per cent) contribution to the diet, include Australian fur seal, New Zealand fur seal, Australasian gannet, short-tailed shearwater, little penguin, crested tern and shy albatross.
- Key areas of importance to these species include south-eastern Australia, especially Bass Strait, Tasmania and SA.
- There remains some uncertainty about other CPF species that might be susceptible to localised depletion since diet information is poor or unavailable.

## 6.7.4 The potential for adverse impacts of localised depletion on CPF species in SPF

There is very limited information currently available that enables the panel to assess the potential for adverse impacts on CPF species in the SPF from localised depletion. As with the global assessment, studies that have identified links between prey abundance and CPF predator performance provide the only types of studies that provide some insight about the likely nature of adverse impacts from localised depletion. There are very few of these available for the key CPF species identified above within the area of the SPF.

#### Seabird response to sardine mortality events

In March 1995 and October 1998, a disease-related mortality event is estimated to have killed approximately 70 per cent of the sardine stock biomass in southern Australia over three to four months (Gaughan *et a*l. 2000, Ward *et al.* 2001a) The cause of the diseases was considered to be an exotic herpesvirus originating in SA which spread 2500 km east and west (Jones *et al.* 1997, Murray *et al.* 2003). This catastrophic event provided a unique opportunity to assess the potential adverse effects on some dependent CPF species when a major prey species suddenly becomes unavailable. Three case studies are summarised below on little penguins, Australasian gannets and crested terns.

#### Little penguins and sardine mortality event

Dann *et al.* (2000) monitored the effects of the major and widespread mortality of sardine that occurred around southern Australia from March to May 1995. They noted that in May 1995, the numbers of little penguins coming ashore declined at Phillip Island and St Kilda concurrently with the recording of many penguin deaths in western Victoria. Around 2.3 per cent of those banded birds at risk of recovery were recovered dead, a much greater number compared to the annual mean of 0.7 per cent (for 1970–1993). The sudden and major absence of sardines following the mortality event is also considered to have had a major impact on breeding success, with birds laying two-weeks later than usual, and only producing 0.3 chicks per pair compared to the long-term average of 1.0 (Dann *et al.* 2000). Dann *et al.* (2000) concluded that both the increase in penguin mortality and the significant reduction in breeding success were associated with the widespread Australian sardine mortality. Breeding success and the number of birds coming ashore had returned to normal levels two years following the sardine mortality event (Chiaradia *et al.* 2010).

#### Australasian gannets and sardine mortality event

Bunce *et al.* (2005) noted a significant decline in the breeding success and chick growth of Australasian gannets in Port Phillip Bay during the 1998–99 breeding period immediately following the major sardine mortality event. The apparent unavailability of sardines following the mortality event was reflected in major declines in the representation of sardines in the diet of gannets, from approximately 60 per cent prior to the mortality event, to 5 per cent following it, which was also coincident with low commercial catches and catch rates of sardine by commercial fisheries (Bunce and Norman 2000). The reduced fledging mass of chicks during the 1998–99 breeding season is thought to have been caused by reduced provisioning, as evident by significantly smaller food samples recorded in the 1998–99 breeding period, indicating that food was indeed limited (Bunce *et al.* 2005). The recovery to normal breeding success in the subsequent Australasian gannet breeding season (1999–2000), despite the continued absence of sardine in their diet is thought to have been facilitated by the expansion in the distribution and abundance of other small, inshore pelagic schooling fish, such as anchovy, following the sardine mortality (Ward *et al.* 2001a, Bunce *et al.* 2005). Sardine abundance in the diet of Australasian gannets has shown a strong correlation with local commercial catches and catch rates, suggesting that the relative proportion of sardine in the diet may be a useful index of sardine abundance (Bunce 2004).

#### Crested terns and sardine mortality event

McLeay *et al.* (2009) studied a population of crested terns at Troubridge Island in Gulf St Vincent, SA, taking advantage of a banding program where around 1350 chicks have been banded in most years since 1975. They investigated the diet, age structure, and morphology of the crested tern population to determine if survival and growth of adults was reduced for cohorts reared in years immediately following the sardine mortality events. Both anchovy and sardine are important prey species for crested terns, representing 36 per cent and 15 per cent of the prey fed to chicks, respectively. Based on the recaptures of adult birds during breeding seasons, McLeay *et al.* (2009) determined that crested terns were physically smaller and had lower survival rates in years following the two sardine mass mortality events in 1995 and 1998.

#### Potential CPF ecological performance indicators in the South Australian sardine fishery

As part of a study examining the potential use of EPIs and reference points to assess the need for ecological allocations in the SASF, Goldsworthy *et al.* (2011) developed a suite of reproductive and foraging success parameters of key CPF seals and seabirds to compare against annual changes in sardine catch and estimated spawning biomass. A total of 181 potential EPIs were used to describe trends in abundance and breeding success and feeding ecology of crested terns (44 EPIs), New Zealand fur seals (66 EPIs), little penguins (54 EPIs), short-tailed shearwaters (17 EPIs), that were compared to five sardine indicators (three biomass and two catch), resulting in a total of 905 relationships (Goldsworthy *et al.* 2011). Negative correlations were observed between sardine annual catch and the morphology and growth of New Zealand fur seal pups, the breeding success of little penguins, the morphology of crested terns and the growth of shearwaters. However, for most species, the EPI times series were too short (three to four years collected over the period of the study) to enable robust analyses and, as a consequence, the number of significant correlations detected for species' EPIs did not differ from that expected by chance alone (Goldsworthy *et al.* 2011). It was also noted that sardines were only a minor part of the diet of New Zealand fur seals, little penguins and short-tailed shearwaters, and that their foraging areas did not significantly overlap with the area of the SASF. Because of the very short time series and unclear trophic and spatial overlap between the fishery and some of the predators, the authors expressed the need for caution when interpreting the results and noted that longer time series were needed to enable more robust analyses.

#### Summary: potential for localised depletion on key CPF species in the SPF

- As with the global assessments, studies that have identified links between prey abundance and CPF predator performance are the only types of studies that provide some insight about the likely nature of adverse impacts from localised depletion. There are very few of these available for the key CPF species identified within the area of the SPF.
- Studies on little penguins, Australasian gannet and crested terns—following the sardine mortality events of 1995 and 1998, that were estimated to have killed around 70 per cent of the sardine stock biomass in southern Australia over a short period—provide some insight on the potential impacts on CPF predators when a major prey species suddenly becomes unavailable. Impacts included dietary shifts, reduced provisioning rates and chick, juvenile and adult survival.
- A study undertaken in SA attempted to identify a suite of reproductive and foraging performance indicators in four CPF predations to potentially act as EPIs for the SASF. However, the short time series (three to four years) for most species precluded a meaningful conclusion.
- There is a potential for localised depletion to impact CPF predators in the SPF since there is very limited monitoring of CPF predator populations and the chance of detecting any indirect fishery-related impacts within the SPF area is extremely low.

# 6.8 Assessment of adverse impacts arising from any localised depletion by the DCFA

#### 6.8.1 Focus of assessment

Under the definition of localised depletion adopted by the panel, it is inevitable that the DCFA will result in localised depletion. The nature of the potential adverse environmental impacts that might arise from localised depletion in the SPF under the DCFA has been discussed above. The panel considered that the greatest potential for adverse impacts relates to CPF species, and its assessment was focused on these species. However, the panel noted that SBT while not a CPF, is a protected species (conservation-dependent) predator of SPF target species and this species was included in the panel's assessment.

#### 6.8.2 Adverse environmental impacts

Whether or not there are adverse environmental impacts on protected species of central place foragers and SBT arising from localised depletion caused by the DCFA, and the extent of any such impacts, will depend on:

- the species that is locally depleted
- the area over which the depletion occurs and quantitative extent of that depletion
- the time taken for the depletion to be corrected
- the spatial and temporal overlap of the localised depletion with key foraging and/or breeding grounds and key times of the year for CPFs
- the nature and extent of reliance of SBT on the species that is locally depleted.

Our understanding of each of these factors in the context of the DCFA fishing scenario is discussed below.

#### The species depleted

As discussed above, the spatial, quantitative and temporal extent of localised depletion is likely to vary across the main SPF target species. As noted in Section 6.4.2, these species have some inherent characteristics that make them vulnerable to localised depletion, but have other characteristics that are likely to reduce the temporal and spatial extent of any such depletion and adverse environmental impacts on predator species that might arise. The target species vary in size, age and specific habitat preferences and their resilience to fishing impacts varies.

However, we know little about their finer-scale movement patterns or site fidelity. This has implications for the nature and extent of potential adverse environmental impacts on predator species, since their reliance on the target species varies. The data provided in Tables 4.1 and 4.2 (Chapter 4) suggest that the CPF species that rely heavily on one or more SPF target species are the Australian fur seal, New Zealand fur seal, Australasian gannet, common dolphin *Tursiops truncatus*, short-tailed shearwater, shy albatross and crested tern and, to a lesser extent, little penguin. SBT also relies heavily on these species.

#### Location and spatial extent of the depletion

Where localised depletion occurs depends upon the distribution of the target species, their availability in a particular season and the economics of fishing (costs and market price). The panel considered that the main target species of the DCFA are jack mackerel, blue mackerel and redbait.

The historical pattern of fishing for these species in the SPF has been dictated largely by the availability of fish and their proximity to ports. A key rationale for the DCFA is that it can fish further away from ports so the historical pattern of fishing is not necessarily a good guide to the spatial distribution of fishing effort under the DCFA. However, the SPF target species are distributed predominantly on the shelf and slope (see Figures A4.1 to A4.4 in Appendix 4) and the panel has assumed that most fishing by the DCFA will occur in these areas of the SPF.

The spatial extent of any localised depletion will depend on the distribution and movement patterns of the species targeted. The quantitative extent of localised depletion of any of the target species will depend on catch rates of the target species and how long those catch rates remain sufficiently high to support the fishing operation. Catch rates will depend on the availability and catchability of fish. Availability depends on environmental conditions that influence the schools' behaviour and which fluctuate seasonally and inter-annually, and the number of, and biomass of, schools in the area. Catchability depends on behavioural characteristics of the fish such as schooling, which affects the density of aggregation within a school and the ability to avoid the fishing operations, and the characteristics of the fishing gear, method and fishing strategy.

Given the range of factors in play, the panel cannot predict with any certainty the location or the extent of localised depletion under the DCFA.

#### The temporal extent of depletion

The persistence of localised depletion caused by the DCFA will depend on how much is removed from a particular area, target species mobility, and the frequency and intensity of the fishing pressure. The SPF target species vary in size, age and habitat preference, however they are mobile and fast swimmers and are not confined to embayments, estuaries etc. that would impede movement or mobility.

The panel cannot predict with any certainty the temporal extent of localised depletion under the DCFA. However, all the information available to the panel confirms that the high mobility of SPF target species is likely to reduce the temporal extent of localised depletion relative to more sedentary species.

#### Spatial and temporal overlap with central place foragers and SBT

#### **CPF** species

Because CPF species (seabirds and pinnipeds) raise offspring on land, they have a high dependency on near-colony prey resources at certain locations and times (Figure 6.7 and Table 6.2). This increases their vulnerability to localised depletion of prey in their key foraging areas. The CPF species most susceptible to localised depletion of SPF target species have been identified by taking into account both their dietary reliance on SPF target species and their reliance on nearcolony prey resources while raising offspring. They are Australian fur seal, New Zealand fur seal, Australasian gannet, short-tailed shearwater, little penguin, crested tern and shy albatross. However, the dietary data available for CPFs in the area of the SPF are by no means comprehensive and therefore this list of most susceptible species is unlikely to be comprehensive.

The information available on key areas of critical foraging habitat for these CPF species in the SPF is variable and there are few studies (Section 6.7.4) that have examined the potential impact of localised depletion on these species.

As discussed above, it is not possible to accurately predict whether and where localised depletion might occur or how long that depletion might persist under a DCFA. The DCFA has a greater ability to range away from ports and there is, therefore, the potential for increased exposure of more CPF colonies to fishing by the DCFA. Conversely, the DCFA has an increased ability to avoid those areas or move out of them if a problem occurs, since it has more options available to it than smaller vessels

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SPECIES	FORAGING MODE	J	A	S	0	N	D	J	F	М	A	м	J
Australian fur seal	benthic												
New Zealand fur seal	pelagic												
Short-tailed shearwater	plunge dive												
Little penguin Vic./Tas./NSW	pelagic												
Little penguin SA/WA	pelagic												
Australian gannet	plunge dive												
Crested tern	plunge dive												
Shy albatross	surface feeder												

Figure 6.7 Approximate timing, by month, of breeding and offspring growth for key CPF predators in the SPF area (light blue). The periods of greatest vulnerability to CPF predators' (incubation, chick feeding, early lactation) when offspring are young are indicated in dark blue. General foraging mode is also indicated. Source: adapted from Patterson *et al.* (unpublished) and S. Goldsworthy, SARDI, unpublished data.

Table 6.2 Examples of satellite telemetry studies undertaken on key CPF predators in the SPF area, detailing the average foraging distances and bathymetry. Type of tag indicates GPS or Platform Transmitter Terminal (PTT) (Argos transmitter). AF = adult female.

SPECIES	LOCATION	SAMPLE SIZE	DISTANCI	E (KM)	BATHYMETRY (M)		TAG TYPE	SOURCE
			AVERAGE	SD	AVERAGE	SD		
Australian fur seal	Kanowna Is., Victoria	71	18.2	45.0	34.5	19.6	GPS	Patterson <i>et al.</i> unpublished
Australian fur seal	Four sites, Victoria <sup>1</sup>	48	120.5	142.5	48.2	70.5	PTT	Patterson et al. unpublished
New Zealand fur seal	Kanowna Is., Victoria	6	23.0	95.9	34.0	192.8	PTT	Patterson <i>et al.</i> unpublished
New Zealand fur seal (AF)	Four sites, SA <sup>2</sup>	44	53.0	51.4	81.0	33.1	PTT	Goldsworthy <i>et al.</i> 2011
Short-tailed shearwater	Griffith Is.	40	6.9	20.1	12.0	95.4	GPS	Patterson <i>et al.</i> unpublished
Short-tailed shearwater	Gabo Is.	47	7.7	11.9	27.6	26.9	GPS	Patterson <i>et al.</i> unpublished
Short-tailed shearwater	Althorpe Is., SA	22	39.2	27.0	79.9	27.0	PTT	Goldsworthy <i>et al</i> . 2011
Little penguin	Gabo Is.	117	16.6	15.7	131.0	283.5	GPS	Patterson et al. unpublished
Little penguin	London Bridge	98	10.1	9.3	49.1	21.7	GPS	Patterson <i>et al.</i> unpublished
Little penguin	Seven sites, SA <sup>3</sup>	85	14.2	13.9	35.6	15.2	PTT	Goldsworthy <i>et al.</i> 2011
Australian gannet	Point Danger, Victoria	69	30.2	71.5	58.1	392.1	GPS	Patterson <i>et al.</i> unpublished
Australian gannet	Pope's Eye, Victoria	141	19.5	37.7	9.7	22.1	GPS	Patterson et al. unpublished
Crested tern	Troubridge Is., SA	22	35.0	11.4	22.0	11.6	GPS	Goldsworthy <i>et al.</i> 2011

1 Seal Rock, Lady Julia Percy Is., Kanowna Is., The Skerries; 2 Cape Gantheaume, Cape du Couedic (Kangaroo Island), North Neptune Is., Liguanea Is.; 3 Granite Is., West Is., Olive Is., Pearson Is., Reevesby Is., Troubridge Is., Kingscote (Kangaroo Is.)

#### SBT

The few dietary studies of SBT indicate a high reliance on SPF species in Australian waters depending on region, i.e. sardine in the GAB and redbait and jack mackerel off southern and eastern Tasmania respectively (Table 4.2). However, SBT is a single stock, highly migratory species whose pelagic habitat includes both the high seas and the exclusive economic zones of various countries. SBT has even greater mobility than the target species and is able to forage widely often in association with oceanic features such as frontal systems. It is highly unlikely that localised depletion of SPF target species would cause adverse environmental impacts on a pelagic predator such as SBT. Under these circumstances, any spatial and temporal concentration of fishing effort by the DCFA in the SPF, under sustainable catch limits, is unlikely to have significant adverse impacts on SBT.

#### 6.8.3 Relevance of vessel and gear to localised depletion

A common concern expressed by some stakeholders was the greater capacity of the DCFA to catch fish compared to the fishing fleet in the SPF, which currently consists predominantly of purse seine fishing vessels but has in the past included one or two mid-water trawl vessels. Purse seines have been used traditionally in Australian fisheries for jack mackerel, Australian sardines and tuna. The carrying capacity of a purse-seiner is proportional to the vessel size. The carrying capacities of the purse seiners operating off Tasmania in the 1980s were between 120 t to 400 t. That fleet landed a maximum annual catch of 41,000 t of jack mackerel—four times greater than the entire current Eastern Zone TAC for that species—for nearly four years, of which the smaller vessels accounted for 60 per cent (Williams and Pullen 1993). Purse-seiners operating in the GAB capturing juvenile SBT for wild-fish farming are similarly-sized with 200–600 t fish holding capacity (International Seafood Sustainability Foundation 2013). Some of these vessels could also operate in the SPF.

The proposed DCFA fishing scenario uses a mid-water trawl, also referred to as pelagic trawl (see Box 3.2). Unlike purse seining which encircles schools of fish with a net (see Box 3.1), the mid-water trawl net is towed through a school of fish. In Australia, mid-water trawling is used in fisheries such as the winter blue grenadier fishery in the Commonwealth Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery (SESSF), and in the Heard Island and McDonald Islands (HIMI) mackerel icefish fishery. Many small pelagic species are targeted by mid-water trawling in international fisheries, e.g. capelin *Mallotus villosus*, sardines, herrings, mackerels, blue whiting *Micromesistius poutassou* and pollock. The vessels usually tow at 3.5 knots or more depending on the swimming ability of the target species.

Mid-water net configuration can vary hugely with total mouth opening areas varying from 200 to 20,000 m2 (Freon and Misund 1999). The pelagic nets that have been commonly used in mid-water research in southern Australia are the Engels 308, Engels 152, Isaac-Kidd Midwater Trawl and International Young Gadoid Pelagic Trawls, more recently with specialised opening and closing devices attached (Webb and Grant 1979, Maxwell 1982, Young and Blaber 1986, May and Blaber 1989, Young *et al.* 1996, Kloser *et al.* 2011). These nets have relatively small mouth openings in the order of less than 500 m<sup>2</sup> (CSIRO unpublished data). May and Blaber (1989) used an Engel 152 pelagic net off east Tasmania to catch mesopelagic and pelagic fishes (i.e. jack mackerel) for abundance estimates with dimensions of headline length 49.3 m, headline height 13–13.75 m, wingspread 16–24 m giving mouth area of 200–300 m<sup>2</sup>.

Commercial nets used in the mid-water trawl fishery for blue grenadier are generally larger than the research nets. In 2004 FV Aoraki used a net with headline length of 242 m and a mouth area of 7500 m<sup>2</sup> (Kloser *et al.* 2011). The panel heard that smaller nets are currently used in that fishery (e.g. nets with a headline length of 171.5 m and a mouth area of around 3000 m<sup>2</sup>) (Mr. L. Scott, Australian Longline Pty Ltd *in litt.* 9 October 2014). The ecological risk assessment of the SPF mid-water trawl sector (Daley *et al.* 2007b) was based on a net with a mouth area of approximately 1500 m<sup>2</sup>.

The net used in the DCFA fishing scenario has a headline length of around 80 m and height of around 35 m. The panel heard that "Larger nets than that used in the DCFA fishing scenario are common in the commercial pelagic trawl fishing industry sectors" (Mr M. Exel, Austral Fisheries *in litt.* 3 July 2013). The panel noted that the nets used in the Dutch mid-water trawl freezer vessel fishery, have net openings of 30 to 60 m and horizontal spread of the wings from 80 to 120 m (Couperus *et al.* 2004) and that in the pelagic freezer trawler fishery off Mauritania net openings are around 90 m by 50 m (Zeeberg *et al.* 2006).

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Factors such as the power of the vessel, and sounding and sonar equipment, enable modern vessels to be more effective at finding and catching fish. Greater power enables the vessels to tow and manoeuvre larger nets faster. For best performance, mid-water nets are designed to be towed at certain speeds: small pelagics can usually be caught by towing at 3–5 knots while larger pelagics require higher speeds. Auto-trawl systems are now regularly employed to maintain nets in optimal position to allow greater catching ability.

On-board factory/freezing facilities allow vessels to stay at sea for much longer but also allow a better quality product. There are several vessels of this type operating in Australian fisheries acting as carrier vessels supplying freezer capacity to smaller fishing vessels, as in the Northern Prawn Fishery, and freezer vessels using mid-water trawl gear also operate in the HIMI fisheries and in the winter fishery for blue grenadier in the SESSF.

The DCFA could carry sufficient fuel to enable it to stay at sea for extended periods of up to three to four months, but port visits to unload fish are likely to occur every six to eight weeks. Based on similar vessels, the panel has assumed that the factory processing plant could process 250 t of fish per day, thus limiting the optimal daily fish catch. The panel heard from experts that, historically, the average catch (shot) in the mid-water trawl fishery for redbait in the SPF was 60–100 t, and that with net monitors, fishers are able to end a tow when the net reaches optimum capacity (approximately 60–100 t) to enable and ensure efficient handling and processing. The panel heard that the proposed target optimum catch size for the *FV Abel Tasman* would have been similar to that used on the most recent mid-water trawl vessel to operate in the SPF (Mr G. Geen, Seafish Tasmania Pty Ltd, pers. comm. 23 April 2013).

When exploring the claim that a large mid-water trawl freezer vessel is more likely to cause localised depletion than a fleet of smaller vessels, the panel heard that: "Where the resources permit (abundance, aggregation and schooling density) larger trawl vessels can clearly catch more fish, more quickly than smaller trawlers. Linking this ability to make large catches to cause of local depletion is a big jump and it is not clear that a 'super trawler' is more likely to cause local depletion than a fleet of smaller vessels working the same school structure of fish. Such concerns may arise, and be more supportable, in areas where management is weak" (Mr D. Turner, Ministry for Primary Industries New Zealand *in litt* 25 June 2014). Also, the panel was informed that "larger vessels will have a higher catch rate threshold to remain profitable and thus they will have a greater incentive to move from an area beginning to suffer from depletion than smaller vessels that will remain profitable at lower catch rates" (Mr D. Turner, Ministry for Primary Industries New Zealand, *in litt.* 25 June 2014).

# Panel assessment: potential for the DCFA to cause localised depletion that has adverse environmental impacts on CPF species

- The overall catch of the DCFA is likely to be higher than that of the current vessels in the SPF fleet. It is possible therefore that the quantitative extent of localised depletion may be higher than for a single wet boat, but not necessarily for a fleet of wet boats.
- The DCFA is likely to be more efficient in its operations, and has greater ability to catch the quota available.
- Compared to smaller wet boats, the DCFA:
  - can range faster and farther afield in search of fish and for extended times
  - is more likely and is better able to leave an area when catch rates decline, thus reducing the potential for localised depletion arising from its operations to have adverse impacts on CPF species.
- The size of the net in the DCFA fishing scenario is similar in size to the net currently used in the Australian winter blue grenadier mid-water trawl fishery and smaller than some nets used in other Australian mid-water trawl fisheries and in international pelagic fishing fleets.
- The vessel used in the DCFA is larger in length and storage capacity than vessels already operating in Australian fisheries but its ability to locate and catch fish is not dependent on its size per se.
- The ability to 'stay on a school of fish' is largely dependent on the schooling behaviour of the fish and the DCFA has no advantage over smaller vessels in this regard. While the DCFA has greater capacity to resume targeting schools in an area, since it can stay in the area for longer than 'wet boats', it cannot be assumed that the DCFA would be fishing the same, reformed, school of fish on multiple occasions.

- Whether the localised depletion arising from the DCFA causes adverse environmental impacts on CPF species will depend on all of the factors discussed in Sections 6.8.2 and 6.8.3. The key distinguishing feature between the DCFA and current and historical fishing operations in the SPF is that it can stay at sea longer and fish more extensively.
- The DCFA has greater ability to range further than smaller vessels, and the potential to operate in close proximity to more colonies of CPFs and their foraging zones exists, but the spatial and temporal distribution of fishing effort cannot be predicted with any confidence.
- The DCFA, like any fishing operation in the SPF, has the potential to have adverse impacts on CPF species through localised depletion. While it is possible to identify the species most at risk (see Section 6.8.2), it is not possible to quantify the extent of any such impacts.

#### 6.8.4 Management of adverse environmental impacts of localised depletion

The management arrangements for the SPF include three main mechanisms that can contribute, directly or indirectly, to managing the risk of localised depletion in the fishery or responding to it if detected. In broad terms these relate to:

- 1. management settings, including the use of precautionary reference points in the harvest strategy
- 2. zoning of the stocks and quota statutory fishing rights (SFR)
- 3. prescribed responses to localised depletion.

The management measures proposed to apply to the DCFA, do not, in the panel's opinion, attempt to manage the risk of adverse environmental impacts of localised depletion arising from the DCFA. The DCFA would be subject only to those broad measures that apply to the fishery as a whole. These are discussed below.

#### Management settings

It is increasingly recognised that small pelagic species, including at least some of those fished in the SPF, need to be managed to more conservative biomass levels than that associated with maximum sustainable yield  $(B_{MSY})$  (Pikitch *et al.* 2012, Smith *et al.* 2011). Pikitch *et al.* (2012) recommended that "in most ecosystems, fishing should be half the conventional rate (50 per cent of unfished biomass  $(B_0)$ ) or less and leave at least twice as many forage fish in the ocean". For fisheries where little is known about the forage fish and their interactions with predators and the environment, Pikitch *et al.* (2012) recommended that at least 80 per cent of the estimated unfished forage biomass be maintained for those in the 'low information tier', 50 per cent in the 'intermediate' tier and 30 per cent in the 'high information tier'. The panel considered that the SPF fell in between the 'intermediate' and 'high' information tiers as defined by Pikitch *et al.* (2012). The current highest exploitation rate for the SPF ensures that 80 per cent of spawning biomass is maintained. This meets and exceeds the recommendation for the intermediate to high tiers.

The Commonwealth Harvest Strategy Policy (DAFF 2007) requires that all Commonwealth managed fisheries are managed to MEY, which is more conservative than MSY. The default Harvest Strategy Policy target is  $B_{48}$ , however, the SPF Harvest Strategy takes into account the ecological importance of these species and has a higher target reference point. Therefore, harvest rates are set at considerably lower levels than they would be if they targeted MEY (Smith 2011 cited in AFMA 2008).

The extent to which the current harvest strategy settings and exploitation rates account for potential trophic impacts of fishing these species is currently being investigated (FRDC project 2013/028). Preliminary results from that analysis suggest that the trophic impacts of fishing SPF stocks on predators and other parts of the food web are low and this suggests that "based on current evidence, biomass targets and corresponding exploitation levels in the SPF harvest strategy need not be adjusted specifically to account for trophic impacts of fishing" (Dr A. Smith, CSIRO *in litt.* 6 June 2014).

The SPF Harvest Strategy claims to be deliberately precautionary and to take account of the ecological importance of SPF species as key prey species. However, this relates to the broad 'ecological' importance of SPF target species in the ecosystem. It does not suggest that the Harvest Strategy is concerned with ensuring that a temporary depletion of a target SPF stock at a local level does not have an adverse effect on one or more CPF species at a particular point in time. For example, Pikitch *et al.* (2012) recommended that, regardless of the information level, managers should consider when and where to allow fishing, noting that "it may be appropriate to close forage fisheries during spawning season or around

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colonies of seabirds that rely heavily on forage fish". Smith *et al.* (2011) also noted that targeted spatial closures that reduce impacts on predators should "help inform harvest strategies that achieve ecological objectives". They also recommended that forage fish be managed "with predators in mind" and that a "dependent predator performance criterion" be adopted that specifies a management objective of "ensuring that there is a greater than 95% chance that predators do not become vulnerable to extinction, as determined by international criteria".

#### Zoning

In 2007, the Small Pelagic Fishery Management Advisory Committee (SPFMAC) recommended that the fishery be managed as having stocks east and west of 146°30'E based on Bulman *et al.* (2008). In doing so, the committee noted that:

- the evidence for a stock delineation for redbait at that point is not as strong as that for the other key species, but that industry experience supports a separation
- while there is some evidence that separate stocks occur in the far west of the fishery, there is no strong basis upon which to recommend a meaningful boundary to further split the Western Zone (SPFMAC 2007)
- the potential for separate stocks in the Western Zone related largely to blue mackerel (Bulman et al. 2008).

The target species have since been zoned into broad Eastern and Western stocks and quota SFRs allocated accordingly (see Chapter 3). This ensures that fishing effort is spread across the acknowledged stocks of these species.

More recently, Ovenden (unpublished) suggested that overlapping but genetically distinct populations of jack mackerel and sardines probably occur. Knowledge about genetically distinct spawner groups is essential for the sustainable management of the SPF fishery. However, the panel noted that there is some inertia to using genetics as a tool to identify stocks (Dichmont *et al.* 2012).

There is currently no additional information that might better inform a review of stock structure and potential substructuring of stocks, therefore, it is uncertain how to detect, manage or mitigate for adverse impacts of localised depletion within genetically distinct populations.

In relation to the potential contribution of the Eastern/Western Zones to the management of potential localised depletion impacts on CPF species, the panel noted that the zones are extensive geographically. For example, the Western Zone is a huge geographical area but under the current arrangements the whole of the Western Zone TAC for a target species could be taken in a relatively small area of that Zone and in an unrestricted time frame. While the South-east Commonwealth Marine Reserve Network and Great Australian Bight Marine Park (see Section 3.2.4) exclude mid-water trawling from some areas of the SPF, these exclusion areas do not address the needs of CPF species specifically.

#### Responses to localised depletion

Localised depletion remains undefined in the SPF Harvest Strategy. The need for a definition and for the management objectives around localised depletion to be clarified in the Harvest Strategy were identified by Knuckey *et al.* (2008). Small Pelagic Fishery Resource Assessment Group (SPFRAG) has developed a draft working definition (see Section 2.2.4). Nevertheless, the SPF Harvest Strategy provides that if, as a result of fishing, there is evidence of localised depletion or a concerning trend/change in age/size structure, SPFRAG must recommend one or more of the following:

- an appropriate reduction in the RBC and/or
- appropriate spatial or other management measures.

In addition, while the following provision of the SPF Harvest Strategy (AFMA 2008) is not linked directly to localised depletion, it could be invoked in response to a localised depletion event that resulted in a detectable change in ecosystem function:

"If, as a result of fishing in the SPF, there is evidence of changes in ecosystem function (e.g. reduced breeding success of seabirds), SPFRAG must recommend one or more of the following:

- an appropriate reduction in the RBC and/or
- appropriate spatial or other management measures and/or

- that a program be established to:
  - i) assess the potential impacts of the fishery on the ecosystem
  - ii) investigate potential ecological performance indicators for the fishery
  - iii) report management performance against those indicators."

In addition to the responses included in the SPF Harvest Strategy, AFMA has powers under the *Fisheries Management Act 1991* to issue a 'direction' in response to the need for immediate action in any fishery. The panel noted that any adverse environmental impacts on CPF species are unlikely to be detected until well after the fishing event, thus mechanisms that provide for immediate action are less relevant in this instance.

## Panel assessment: proposed measures to manage the risks to CPF species arising from localised depletion caused by the DCFA

- The overall level of exploitation permitted in the SPF appears to be consistent with the best available advice on management of small pelagic species.
- At a fishery wide and zone level, the exploitation rates applied in the SPF Harvest Strategy may adequately account for tropic impacts.
- The precaution that is inherent in the SPF Harvest Strategy settings is unlikely to make a significant contribution to avoiding adverse environmental impacts of localised depletion on CPF species since the TACs set under the Harvest Strategy can be taken in any area of the East or West Zones.
- The provisions of the Harvest Strategy do not provide a mechanism to detect or manage the risk of localised depletion having adverse environmental impacts on CPF species. Rather, these provisions outline responses to localised depletion once it has been detected.
- There are no measures in place in the SPF or proposed for large-scale mid-water trawl operations, that would detect the spatial and temporal extent of localised depletion or adverse environmental effects that arise from it.
- There are no spatial and temporal closures in place, or proposed, for large-scale mid-water trawl operations that address potential trophic impacts to CPF species in the SPF.
- The measures proposed to apply to the DCFA did not include any that would be effective in minimising the risk of adverse environmental impacts on CPF species that might arise from localised depletion caused by the DCFA.

## 6.8.5 Actions that could be taken to manage localised depletion in the SPF

It is not possible to accurately predict the extent of any adverse environmental impacts on CPF species arising from localised depletion under a DCFA. However, it is possible to identify species, times and areas that, subject to the spatial and temporal extent of such depletion, may be most susceptible to it. This allows for management of the risks of such impacts occurring.

As detailed in Section 6.7, there are very few examples where impacts of fishing on CPF predators have been shown to be directly caused by localised depletion. Due to the large uncertainty in the impacts of fishing on the marine ecosystem and CPF predators, and the challenges in attributing cause and effect, in most instances where there are concerns over the potential adverse impacts of fishing on CPF species, some form of precautionary management has been considered.

There are three main precautionary management approaches that could be implemented in order to mitigate the potential adverse impacts of localised depletion caused by the DCFA on CPF predators. These are discussed below.

#### Spatial allocation of TAC

The use of spatially allocated TACs would require the SPF fishery to be managed in smaller spatial management units within which the consumption needs of predators of SPF species (including CPF) would be assessed and taken into account. Area-specific TACs would be set for each management unit. However, unless the management units are

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relatively small in scale, spatial allocation may not prevent most of the allocated catch within a management unit being taken in a small geographic space over a short time period, and as a result this may be a less effective management tool to mitigate the potential impacts of localised depletion on CPF predators.

#### Move-on rules

Move-on rules could be applied to critical foraging zones of CPF predators and/or at critical times, for example during breeding season, chick or pup rearing periods, to manage the potential adverse impacts from localised depletion by the DCFA on CPFs. These rules are a form of spatial closure that is enforced after a certain level of catch has been taken within a sensitive CPF area and at sensitive times.

The panel understands that, after consideration of various options to address the risk of 'localised depletion' SPFRAG is focusing its effort on the use of move-on rules (SPFRAG 2014a). The panel noted that SPFRAG has previously discussed how the fishing activity of the proposed large mid-water trawl freezer vessel might be monitored in space and time, particularly in the context of the data confidentiality rules that apply to commercial fishing data, including 'the five boat rule' (AFMA 2014e). The panel agrees that, should a move-on rule be adopted for the purposes of spreading catch (as distinct from avoiding interactions with protected species), then there would need to be greater transparency about the spatial distribution of catch and effort.

In the panel's view there is less information available to inform the setting of a meaningful level of catch over space and time required by a move-on rule than is the case for broader, spatial/temporal closures.

#### Spatial closures

Spatial closures are used to prevent any fishery catch taking place in critical foraging areas, typically adjacent to CPF species' breeding colonies. Closures may be temporary, to protect CPF predators at critical time periods, such as during the breeding season; or permanent, where animals may reside at colonies or haulouts year round, and where offspring may be provisioned over longer time periods (e.g. seals with long lactation periods). Typically, the extent of the spatial closure(s) would be determined by an understanding of where the key foraging areas are, or on limitations in the foraging ranges or spatial at-sea distribution, and would potentially vary among species and populations in their scale, timing and duration. The panel noted that the use of spatial/temporal closures has been discussed by SPFRAG (2014a) and that there was some support in the group for such an approach if sufficient information is available to establish meaningful closures.

Globally, spatial closures are the most common form of precautionary management of the potential adverse impacts of localised depletion on CPF predators. Examples of these are detailed in section 6.7.2. Critically, for none of these examples has the effectiveness of spatial closures in preventing adverse environmental impacts to CPF predators been clearly demonstrated.

A key challenge for the introduction of spatial management into the SPF for the purposes of managing the potential adverse impacts of localised depletion on CPF predators, would be to determine the scale of spatial closures that would be appropriately precautionary for particular species at particular locations and at particular times. For some areas of the SPF, such as the waters off SA and to a lesser extent Bass Strait, there are reasonable datasets on species distributions, some data on relative abundances, diet and foraging behaviour (Goldsworthy *et al.* 2011, Patterson *et al.* unpublished). In these regions, use of the available movement, foraging and diet data for some CPF species may be sufficient to design and evaluate suitable spatial management strategies to manage the potential adverse risks to CPF populations from localised depletion. However, elsewhere throughout the SPF, CPF populations. There may be challenges in extrapolating the at-sea distribution models developed for those regions where there are sufficient data, to those where there are not (Patterson *et al.* unpublished). However, precautionary spatial closures could be implemented based on the best available data until more relevant data can be obtained.

The panel concluded that should a significant increase in the level of fishing effort in the SPF be envisaged, through the operation of a DCFA, consideration should be given to finer scale management of catch in order to minimise risks associated with adverse environmental impacts of localised depletion on CPF species. As discussed in Section 6.6.5, the identification of smaller-scale management units for which TACs take into account the consumption needs of CPF species may be an option, however, unless these are quite small in scale they may not prevent concentration of the catch in

space and time in areas of key ecological importance. The panel considered that spatial/temporal closures to fishing that specifically address the needs of the identified CPF species were the most appropriate way to manage the risks to these species associated with localised depletion arising from the DCFA. The panel acknowledged that the effectiveness of such closures, for this purpose, has not been clearly demonstrated.

In the longer term, the adoption of finer scale management of stock, i.e. subdivision of the current Eastern and/or Western Zones by species, may also have a role to play in minimising the risk of localised depletion occurring. The panel noted that there is currently no basis on which to make an informed decision on such subdivision. Finer scale management that potentially better reflects population structure will provide additional protection for target stocks and of the role of those stocks in the overall ecosystem. In the panel's view, it will not necessarily preclude adverse environmental impacts on protected species of CPF species. This is because such an approach may not provide the level of protection required by these species, either spatially or temporally.

# Panel advice: actions that could be taken to manage the risks to CPF species arising from localised depletion caused by the DCFA

- There are three main precautionary management approaches that could be implemented to mitigate the potential adverse impacts of localised depletion caused by fishing on CPF predators: spatial allocation of catch, move-on rules, and spatial closures.
- Spatial closures are the most common form of precautionary management used to mitigate the potential adverse
  impacts of localised depletion on CPF predators; however, the effectiveness of spatial closures for this purpose has not
  been clearly demonstrated. Their effectiveness depends heavily on the ability to determine the scale of spatial closures
  that would be appropriately precautionary for particular species at particular locations and at particular times.
- The panel considered that the risks to protected species of CPFs from localised depletion caused by the DCFA should be managed through the adoption of a proactive approach that separates the fishing activity from the key foraging areas and times used by CPF species rather than through move-on rules. This does not discount the potential value of moveon rules in the context of direct interactions with protected species.
- While determining the appropriate scale of the required closures in particular times and areas will remain a challenge, there are reasonable datasets available in at least some areas of the SPF that could inform these decisions. It may be necessary to extrapolate from this information in order to define appropriate spatial closures elsewhere in the SPF.
- It is likely that these spatial closures will need to be modified adaptively to reflect additional information as it becomes available, either through fishing or targeted research.
- Global studies on CPF predators demonstrate that they are responsive to changes in the availability of prey within their foraging range, but they do not distinguish between changes caused by localised and overall stock depletion. Careful consideration of how management of the entire stock, and especially the reduction in available biomass through fishing, impacts on CPF predators at a local scale and at critical times, is required.

## 6.9 Monitoring and research

The panel found no conclusive evidence of historical localised depletion that caused adverse environmental impacts in the SPF. The high level of dependence by some predators, particularly CPF species, highlights the need to manage for the risk of such impacts. It also points to the potential to use populations of these species to monitor the health of the SPF resources.

Many of the uncertainties that have been identified in relation to the panel's ability to assess the extent of local depletion likely under a DCFA cannot be addressed through monitoring and research. Some uncertainties reflect the dynamic nature of the marine environment and consequently, responses of small pelagic species. Some reflect the dynamics of fishing operations and economics. Thus many of the uncertainties will remain and management must, therefore, be precautionary and adaptive.

## 6.9.1 Target species

The panel considered that it is reasonable to expect that a significant increase in catch of SPF target species is only likely to occur under a fleet configuration that involves a capacity to stay at sea longer and to fish the area of the SPF more broadly. That configuration may or may not approximate the specific type of activity specified in the DCFA, but, in any case, this would allow more catch to be taken, within the constraints of the TACs. In order to minimise the risk that fishing is concentrated on sub-populations of redbait, blue mackerel and jack mackerel, further investigation into the population structure of these species may be warranted. In particular, given that more fishing is likely to occur in the Western Zone of the SPF under a DCFA than under the current fleet configuration, further investigation of the possibility of separate stocks of blue mackerel in the Western Zone may be warranted.

Ovenden (unpublished) identified several projects that could improve the understanding of stock structure in the SPF species and hence allow better and more appropriate spatial management for all stocks. More robust spatial management of the stocks should reduce the likelihood and risks associated with localised depletion of those species. The projects identified ranged between a very cost-effective re-analysis of existing jack mackerel and sardine data, if available, using the latest statistical methods, to more targeted studies, at increasing costs, on all SPF species, including blue mackerel, yellowtail scad *Trachurus novaezelandiae* and redbait for which there is very poor information. Some of the latter studies could easily be added into the fishery-independent surveys currently being conducted or planned in the SPF. Ovenden (unpublished) also advocated that a combination of genetics and single-generation markers such as otolith chemistry, parasite, abundance, tagging and tracking, is needed to define stocks and better understand 'crinkles in connectivity between populations' but the panel noted that the SPF has limited resources to support such a range of research programs. The panel supports further well-designed and targeted research in this area to clarify the extent of sub-structuring within the Eastern and Western Zones specifically, and the SPF more broadly.

The panel considered that ongoing monitoring of the length frequency of catch taken by the DCFA will be important for monitoring both overall stock health and detecting any localised effects on target stocks. Given that catch will be frozen onboard the vessel, management measures will need to ensure that arrangements are made for observers to collect this information.

## 6.9.2 CPF species

The panel has determined that there are widespread and large uncertainties in the population status and abundance of CPF predators, the spatial distribution of foraging effort, and the diet of most species. To address these uncertainties and inform about potential impacts of reduction in prey due to SPF depletion within CPF key foraging areas, the panel highlights the following four key research and monitoring needs.

1. Dietary studies to determine which key CPF predators or other commercially or ecologically important predators are most reliant on SPF species

In general, information on the importance of SPF species and other commercially targeted species in the diets of CPF predators is patchy, leading to large uncertainties due to the lack of representativeness in locations and years. For some species the basic information is absent. As a consequence, there may be other species for which there are limited data that may well be susceptible to impacts associated with the SPF.

#### 2. Studies to better understand the critical foraging areas, habitats and times for key CPF species

There are major gaps in information on the distribution of key foraging areas for CPF species throughout the SPF area. Critical gaps include comprehensive and representative data on the foraging distributions and ranges at critical lifehistory stages for seabirds, during incubation and chick rearing to fledging; and for seals, the key foraging areas of adult females throughout lactation. In managing for the potential adverse impacts of localised or stock depletion on dependent CPF predators, such information is necessary to determine the scale of spatial closures that would be appropriately precautionary for particular species at particular locations and at particular times. This does not preclude the introduction of interim precautionary closures based on available information.

#### 208 <u>3. Biological response of key CPF predators to changes in prey availability</u>

There are a number of global studies that provide an important foundation to our understanding of how CPF species respond to variation in prey availability over short and long time scales (see Boyd *et al.* 2006 and chapters therein). Unfortunately, there are few such studies in Australia that can be drawn upon to provide any insight into the likely nature and consequence of indirect fishing impacts on protected CPF species. Long-term monitoring of key CPF species' populations in the SPF area could provide important information on assessing the indirect effect of fishing. Such studies could monitor foraging efficiency, provisioning rates and offspring growth rates and fledging/weaning mass, survival and adult breeding success. Monitoring of annual production and/or population size would also provide very relevant time series and key performance indicators of CPF predator health, and also an indirect measure of the degree to which potential indirect effects of fishing are being managed/mitigated.

#### 4. Establishment of ecological performance indicators

The panel noted the provision in the SPF Harvest Strategy for the establishment of a program to assess the potential impacts of the fishery on the ecosystem, investigate potential EPIs for the fishery and report management performance against those indicators if there is evidence of changes in ecosystem function (e.g. reduced breeding success of seabirds). The panel considered that there would be merit in establishing such a program in a proactive way, i.e. to detect such events, rather than as a response mechanism.

#### Panel advice: research and monitoring to reduce uncertainty associated with the risk of localised depletion

- Well-designed and targeted research to clarify the extent of sub-structuring of SPF target species within the Eastern and Western Zones specifically, and the SPF more broadly.
- Dietary studies to determine which key CPF predators or other commercially or ecologically important predators are most reliant on SPF species.
- Studies to better understand the critical foraging areas, habitats and times for key CPF species.
- Examination of the biological response of CPF predators to changes in prey availability.
- Ongoing monitoring of the length frequency of catch taken by any DCFA at a statistically appropriate sampling intensity.
- Development and implementation of potential ecological performance indicators for the fishery.