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The economic value of South African kelp forests and temperate reefs: Past, present and future

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ABSTRACT

In South Africa, kelp forests and associated temperate reefs dominate the nearshore subtidal zone in the southern Benguela, with kelp forests covering approximately 1000 km of the coastline. These ecosystems provide a range of goods and services that are of immense ecological, social and economic importance. A number of valuable species on these subtidal reefs are overexploited and have reached a state of crisis since the 1990s. Many linefish stocks are considered collapsed or overexploited, West Coast rock lobster populations are estimated to be at <3% of pre-exploitable biomass and abalone are similarly overexploited, with two of the four major historical fishing grounds now closed to fishing. The current value of this ecosystem is estimated at US$ 434 million year^{-1} (ZAR 5.8 billion year^{-1}), of which c. US$ 290 million year^{-1} (ZAR 3.9 billion year^{-1}) contributes to the South African gross domestic product (GDP), with ecotourism contributing almost 40% of this, followed by recreational fishing (28%), and commercial and illegal fishing (c. 15–16% each). Income currently generated by fisheries is greatly reduced, with some sectors worth less than half of their value in the 1990s. Indirect ecosystem services are valued at US$ 144 million year^{-1} (ZAR 1.9 billion year^{-1}) but aren't realised in the country's GDP as they do not provide direct economic value. Given the importance of the Benguela nearshore region to low-income coastal communities, particularly in the face of increased climate variability, striking a balance between rebuilding depleted stocks and meeting the socio-economic needs of those reliant on them will require a renewed focus on coastal research, with an emphasis on co-ordinated interdisciplinary projects.

1. Introduction

Kelp ecosystems dominate nearshore temperate reefs on c. 25% of the world's coastline and have been the focus of much research due to the complexity of biological interactions that structure them, their immense productivity, and their inclusion of species that contribute to global fisheries (Steneck et al., 2002). Kelps themselves are among the most prolific primary producers on the planet, supporting productivity per unit area that rivals that of tropical rainforests (Leith and Whittaker, 1975). They provide biogenic habitat that can enhance diversity and productivity both locally (Dayton, 1985; Duggins et al., 1989; Teagle et al., 2017), and over broader spatial scales through detrital subsidy (Krumhansl and Scheibling, 2012). Kelp forests also support numerous ecosystem services, including commercial fisheries, carbon storage and flux, mariculture, and shoreline protection, valued in the range of billions of dollars annually (Bennett et al., 2016; Smale et al., 2013; Steneck et al., 2002; Vásquez et al., 2014). Given their accessibility and inclusion of valuable species, kelp ecosystems have been harvested for thousands of years and, with the rise and intensification of commercial fisheries over the past few centuries, many are now overfished (Jackson et al., 2001; Steneck et al., 2002; Tegner and Dayton, 2000).

In South Africa, kelp forests and associated temperate reefs are a major ecosystem, which dominates the nearshore subtidal zone in the southern Benguela. Although four species of kelp are found in this region, only two are dominant: *Ecklonia maxima* and *Laminaria pallida*. Of these, *E. maxima* grows in the shallows, forming dense forests with floating canopies, dominating depths down to about 6 m. From there it thins out down to c. 10 m, with fewer plants found >10 m, while *L. pallida* forms a subcanopy, growing beneath *E. maxima*, eventually replacing it in deeper waters (15–30 m). In the northern regions of the South African west coast and in Namibia, *L. pallida* increasingly develops a hollow stipe and dominates the shallows (Rothman, 2015). Both species of kelp span the entire South African west coast and parts of the south-west coast, covering approximately 1000 km of coastline, but are absent from the south-east and east coasts due to the warmer temperatures of the Agulhas Current. These kelp forests host a number of commercially valuable species including the West Coast rock lobster *Jasus lalandii*, abalone *Haliotis midae*, and a variety of fish. Prehistoric exploitation of this shallow subtidal ecosystem dates back at least 10,000 years, after which remains of *J. lalandii* begin featuring in South African middens (Jerardino

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and Navarro, 2002). However, the San hunter-gatherers on the west coast began harvesting shellfish from the intertidal about 60,000–70,000 years B.P. (Volman, 1978) and it is thought that the inclusion of marine resources in the diet of our ancestors in the region was a major contributing factor in the speciation of anatomically modern humans (Compton, 2011). Prehistoric subsistence exploitation targeted a wide range of marine species, up to as many as 35, although mussels and limpets dominated the harvest (Siegfried et al., 1994). In contrast, commercial exploitation has been directed at fewer, highly profitable species that are abundant, easy to collect and available in large quantities over extensive areas (Siegfried et al., 1994).

While much research has been afforded to describing kelp ecosystems and nearshore reefs in the southern Benguela, including their productivity, energy flow and complex species interactions (see Branch, 2008 for a review); there are no studies that evaluate their worth. In this paper we (1) identify the various goods and services that kelp ecosystems provide, ranging from commercial fisheries to coastal protection, (2) evaluate the past, current and future economic worth of kelp forest and temperate reef ecosystems in the southern Benguela, and (3) identify gaps in knowledge and future research directions pertaining to temperate reefs and kelp ecosystems in the southern Benguela.

2. Ecosystem goods and services

Ecosystem goods and services, commonly referred to as just ecosystem services, are the direct and indirect benefits that humans derive from ecosystem functions, which arise from the structure and ecological processes of a particular ecosystem (Costanza et al., 1997; de Groot et al., 2002). There are four key functions that ecosystems perform: habitat, regulation, production and information (de Groot et al., 2002). Kelp forest ecosystems are no different and from these functions, we can derive direct and indirect services and their estimated values.

2.1. Direct ecosystem services

Direct ecosystem services from reefs and associated kelp forests in the southern Benguela are defined as those goods and services that provide a direct economic benefit. These include various fishing sectors (commercial, recreational and subsistence) and ecotourism such as diving, whale watching and eco filming (Table 1).

2.1.1. Fishing

Species that form the bulk of the commercial catches in the southern Benguela nearshore are shown in Fig. 1, many of which are associated with reefs and kelp forests, while all species of economic value associated (in part or fully) with these ecosystems are listed in Table 2.

The seaweed industry in the southern Benguela is based on the collection and harvesting of kelps *E. maxima* and *L. pallida* along the west and south-west coasts, and previously, the collection of beach-cast gracilarioids (*Gracilaria* and *Gracilariopsis* spp.) along the west coast (Table 2). The seaweed industry began towards the mid-1900s when red seaweeds were collected, dried and exported for agar extraction. This was shortly followed by the collection of beach-cast kelps, which were also dried and exported for the extraction of alginate (Anderson et al., 1989). In the 1980s, a local company began harvesting fresh kelp

Table 1
Direct and indirect ecosystem services provided by kelp forest and temperate reef ecosystems.

Direct ecosystem services	Indirect ecosystem services
Commercial fishing	Coastal protection
Subsistence fishing	Carbon fixation
Recreational fishing	Nutrient cycling
Ecotourism	Biodiversity
	Scientific research & education
	Recreation

for the production of a liquid fertilizer and since the 1990s, kelp fronds have been harvested (and fresh beach cast kelp collected) to supply feed to abalone farms (Troell et al., 2006). Kelp harvests have remained fairly stable over the past few years and the resource is considered sustainable and optimally exploited (Department of Agriculture, Forestry and Fisheries (DAFF), 2014). Gracilarioids (red seaweed) were previously harvested as beach-cast from two sheltered bays on the west coast (Rothman et al., 2009), but yields declined in 2007 and since 2008 no commercial collection has taken place. The resource is considered unsustainable (DAFF, 2014).

The West Coast rock lobster has long been fished as subsistence, dating back c. 10,000 years B.P. (Jerardino and Navarro, 2002). The commercial fishery dates back to the late-1800s (Melville-Smith and Van Sittert, 2005) and early regulations pertaining to the recreational fishery appear in the early 1930s (Cockcroft and Mackenzie, 1997). Commercial catches peaked in the mid-1900s but have since declined, largely due to overfishing, but also due to changes in environment, growth rates and geographic shifts (Cockcroft et al., 2008; Melville-Smith and Van Sittert, 2005; Pollock, 1986). Little information is available on recreational and illegal catch, particularly prior to 2008 for the latter. In recent years, recreational fishing seasons have become progressively shorter in an attempt to reduce quotas and rebuild stocks. However, illegal fishing is thought to have increased considerably in the last few years and is estimated to be equivalent to the legal commercial catch (Johnston and Butterworth, 2016a). The resource is considered overexploited and exploitable biomass is currently estimated to be c. 3% of 'pristine' (Johnston, 2015) or less if poaching levels are indeed greater than previously thought. In 2016 *J. lalandii* was considered endangered and red listed by the WWF South African Sustainable Seafood Initiative.

The commercial abalone fishery began in the mid-1900s and although the resource occurs along the west and south coasts, the fishery has historically been concentrated along the south-west coast (Tarr, 1992; see Fig. 1). Abalone numbers have declined substantially since the mid-1990s due to the synergistic effects of ecosystem change (following an eastward shift in *J. lalandii*, a well-known predator) and significant illegal fishing along the south-west coast (Blamey et al., 2010, 2014). This led to the closure of the recreational fishery in 2003/04, followed by a temporary ban on the commercial fishery in 2008/09. Some of the historic commercial fishing grounds are now closed to (legal) fishing and the resource is considered overexploited (DAFF, 2014). Illegal fishing remains rife and far exceeds the legal catch.

Octopuses have historically been fished recreationally as bait and also for subsistence. Although commercial octopus fisheries exist elsewhere in the world, there is no commercial fishery or local market for them in South Africa. An exploratory fishery for the common octopus *Octopus vulgaris* is underway for the second time along the south-west coast to investigate the feasibility of octopus as a commercial resource. The stock status remains unknown (DAFF, 2014).

The large solitary ascidian, *Pyura stolonifera*, known locally as 'red bait' is harvested recreationally for bait, but there is also an exploratory fishery for it in Saldanha Bay along the west coast, which has been in operation since 2009 (DAFF, 2014). Other key invertebrates that are harvested either recreationally or for subsistence include mussels, limpets, and the 'alikreukel' - a giant turban snail (Table 2).

The South African linefishery targets multiple fish species that are caught by handline or rod and reel. Over 200 species are caught in this fishery, although approximately only 30 of these 200 form the bulk of the catches (Griffiths and Lamberth, 2002). The fishery comprises three sectors: commercial, recreational and subsistence. The commercial fishery dates back to the mid-1800s but increased fishing effort, combined with technological advances in the second half of the 1900s, led to the serial exploitation of many fish species, and by the year 2000 many stocks were considered overfished or collapsed (Griffiths, 2000). Despite this, the fishery is still an important contributor to human livelihoods. The recreational fishery plays a significant role in generating employment and revenue, but has also contributed to the overexploitation of many

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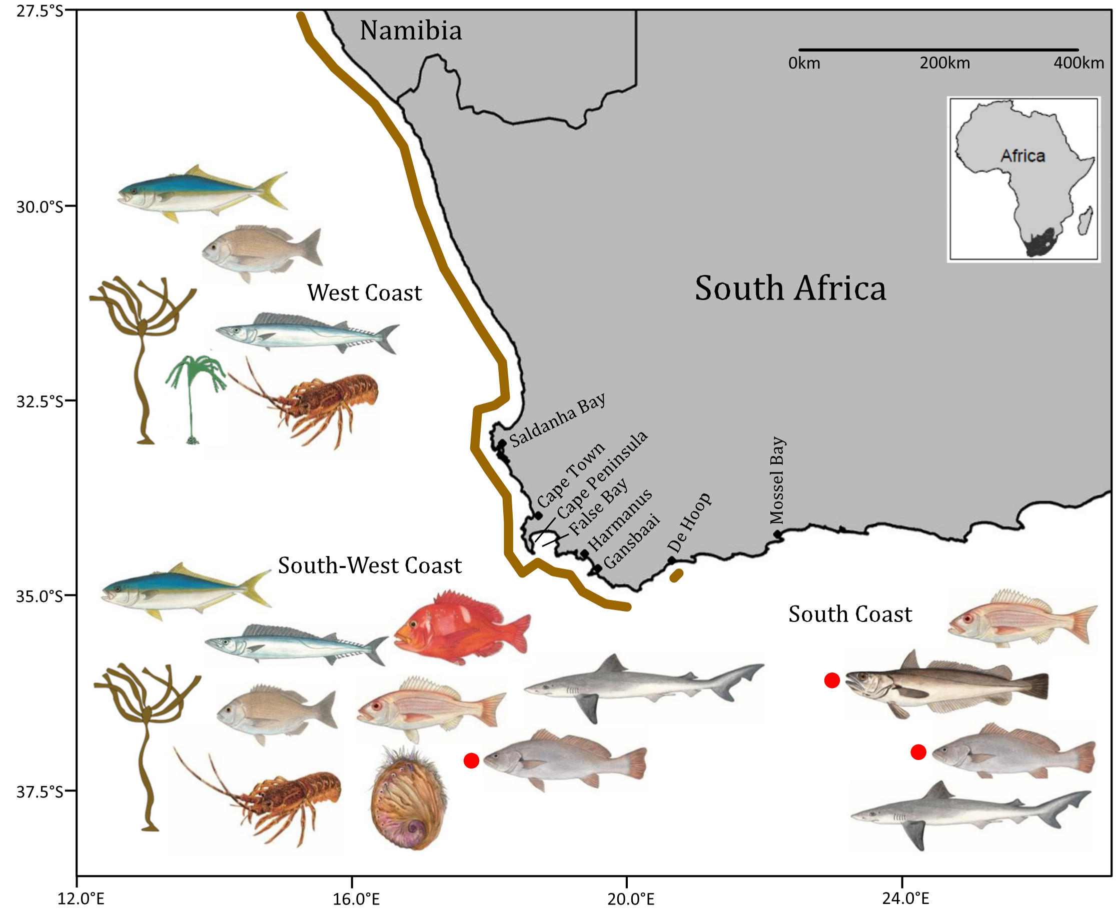

Fig. 1. Distribution of South African kelp forests (brown line) and the main commercial species caught off west, south-west and south coasts (from Blamey et al., 2015). Red circles identify species not associated with reef ecosystems. Drawings reproduced with permission from WWF-SA and the South African Institute for Aquatic Biodiversity (SAIAB). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

species (Griffiths and Lamberth, 2002). In the southern Benguela, there are about 30 species that are associated with rocky reefs and/or kelp forests (Table 2). Of these, most are fished recreationally and more than half are fished commercially. Only four are considered optimally exploited/sustainable, while the rest are fully exploited, vulnerable to overfishing, overexploited, collapsed or status unknown (Table 2).

2.1.2. Ecotourism

The marine tourism industry has expanded rapidly over the last two decades, with boat-based whale and dolphin watching and shark-cage diving the biggest attractions. The shark-cage diving industry centres around the Great White Shark *Carcharodon carcharias* and operates in False Bay, Gansbaai and also further east in Mossel Bay (Johnson and Kock, 2006). In 2013, there were 12 active permits for this industry (Department of Environmental Affairs (DEA), 2014). Various other diving activities also take place in the southern Benguela, including SCUBA diving, snorkelling, and free diving. While diving in temperate waters is not as popular as diving in the tropics or sub-tropics, there are over 100 dive sites in and around the Cape Peninsula and False Bay region, almost all of which are located over rocky reefs, wrecks or in kelp forests. At least 15 dive operators (SCUBA) exist in the region, many of which have dive shops and/or schools attached. Diving takes place all year round, although peak season is in summer, due to adverse weather conditions and storms during winter. Boat-based whale watching occurs along the south-western coast, with peak season occurring from July–November when Southern right *Eubalaena australis* and Humpback *Megaptera novaeangliae* whales overwinter along the South African coastline (Best, 2008). Eco filming has also increased in recent years, with 40 permits having been granted in 2011 (DEA, 2014). Other forms of marine tourism include snorkelling with seals, visits to land-based penguin colonies, coastal hiking trails (e.g. Whale Trail and Otter Trail), fishing charters and Cape Point Nature Reserve, a well-known site for scenic views of the surrounding ocean and kelp forests and also used by recreational and spear fishers.

2.2. Indirect ecosystem services

Indirect ecosystem services are defined as services that are beneficial, but do not provide direct economic value. For nearshore reefs and kelp ecosystems, these include coastal protection, carbon fixation, nutrient cycling, biodiversity, research and education, and recreation (Table 1).

Kelp forests are known for their role in wave attenuation (Jackson and Winant, 1983; Løvås and Tørum, 2001; Mork, 1996) and along South Africa's very exposed coastline, they are often subjected to swells of up to 6 m or more. Kelp forests dissipate this wave energy, providing protection to the coast and refuge to organisms that cannot tolerate such extreme wave action (Velimirov et al., 1977).

Kelps themselves are highly productive organisms and have a high rate of uptake of atmospheric CO_2 (Reed and Brzezinski, 2009). The idea to use algae to sequester carbon from the atmosphere is not new (see Farrelly et al., 2013 for a review) and although kelps have the ability to capture carbon and release oxygen, carbon storage is likely short term and not permanent (Vásquez et al., 2014). Nonetheless, their role in fixing carbon is considered important. Kelps and other macroalgae also play an important role in the recycling of nutrients (Costanza et al., 1997). Much of the nutrient taken up around urban areas is from anthropogenic runoff and an unpublished student report (Cyrus, 2007) used stable

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Table 2
Species associated with South African kelp forest and temperate reef ecosystems that are of economic value, including which fishery targets them and their exploitation status.

Species of economic value	Fishery	Exploitation status
Kelps & seaweeds		
Sea bamboo kelp *Ecklonia maxima*	Commercial	Sustainable
Agar-weed *Gracilaria gracilis*	Commercial (closed)	Collapsed
Invertebrates		
Rock mussels (*Aulacomya*, *Mytilus*, *Choromytilus*, *Perna*)	Recreational	Sustainable
Cape rock oyster *Striostrea margaritacea*	Commercial	Concern surrounding stocks in southern Cape
Abalone *Haliotis midae*	Commercial (recreational closed)	Overexploited
Alikreukel *Turbo sarmaticus*	Recreational	Susceptible to overfishing
West Coast rock lobster *Jasus lalandii*	Commercial & recreational	Overexploited
Octopus *Octopus magnificus*, *Octopus vulgaris*	Exploratory commercial & recreational	Unknown
Redbait *Pyura stolonifera*	Exploratory commercial & recreational	Sustainable if taken from man-made structures
Fish		
Baardman *Umbrina* sp.	Recreational	Susceptible to overfishing
Black musselcracker *Cymatoceps nasutus*	Recreational	Unknown, but vulnerable to fishing pressure
Blacktail *Diplodus sargus capensis*	Recreational	Susceptible to overfishing
Bronze bream *Pachymetopon grande*	Recreational	IUCN near threatened
Cape knifejaw *Oplegnathus conwayi*	Recreational	Unknown
Cape stumpnose *Rhabdosargus holubi*	Recreational	IUCN least concern
Carpenter *Argyrozona argyrozona*	Commercial & recreational	Optimally exploited (previously overfished)
Common smooth-hound shark *Mustelus mustelus*	Commercial	IUCN vulnerable
Dageraad *Chrysoblephus cristiceps*	Commercial & recreational	Overexploited
Dorado *Coryphaena hippurus*	Commercial	Unknown
Elf *Pomatomus saltatrix*	Commercial & recreational	Unknown
Englishman *Chrysoblephus anglicus*	Commercial & recreational	Collapsed
Garrick *Lichia amia*	Recreational	Unknown
Geelbek *Atractoscion aequidens*	Commercial & recreational	Overexploited
Hottentot *Pachymetopon blochii*	Commercial & recreational	Sustainable
Janbruin *Gymnocrotaphus curvidens*	Recreational	Unknown
Panga *Pterogymnus laniarius*	Commercial	Unknown
Roman *Chrysoblephus laticeps*	Commercial & recreational	Previously depleted
Red steenbras *Petrus rupestris*	None (previously recreational)	Overexploited
Red stumpnose *Chrysoblephus gibbiceps*	Commercial & recreational	Overexploited
Santer *Cheimerius nufar*	Commercial & recreational	Unknown
Scotsman *Polysteganus praeorbitalis*	Commercial & recreational	Overexploited
Snoek *Thyrsites atun*	Commercial & recreational	Optimally/fully exploited
Soupfin shark *Galeorhinus galeus*	Commercial	Fully/overexploited
Pyjama shark *Poroderma africanum*	Recreational	IUCN near threatened
White musselcracker *Sparodon durbanensis*	Recreational	IUCN vulnerable
White stumpnose *Rhabdosargus globiceps*	Commercial & recreational	IUCN vulnerable
Yellow-belly rockcod *Epinephelus marginatus*	Commercial & recreational	Unknown/IUCN endangered
Yellowtail *Seriola lalandi*	Commercial & recreational	Sustainable
Zebra fish *Diplodus cervinus hottentotus*	Recreational	Unknown

isotope data to clearly demonstrate the uptake of nitrogen from the Green Point sewage outfall near Cape Town by neighbouring kelps (*E. maxima*).

South African kelp forests have been a valuable source of scientific information. Prior to the 1970s, few studies were conducted on these kelp ecosystems but the Kelp Bed Ecology Programme that took place in the 1970s and 1980s produced an enormous body of research (over 200 peer-reviewed papers, see reviews by Branch, 2008; Branch and Griffiths, 1988; Field and Griffiths, 1991). Since then, there have been a number of specific studies, focusing on trophic interactions or resource use, but no concentrated effort on kelp forest ecology, and in particular little long-term monitoring of kelp forests, as occurs, for example, in Californian *Macrocystis* forests (e.g. Kushner et al., 2013).

These ecosystems also contribute to biodiversity. Marine species richness in South Africa is estimated at around 13,000 species (Griffiths et al., 2010), although species richness is relatively lower on the west coast, compared to the south and east coasts. For some groups e.g. fish, echinoderms, gastropods and bivalves; species richness increases from west to east, while other groups peak in richness along the south-west coast e.g. polychaetes, amphipods and isopods (Awad et al., 2002; Griffiths et al., 2010), or increase in the south west, with richness remaining relatively similar as one moves eastwards e.g. seaweeds (Bolton et al., 2004; JJ Bolton and RJ Anderson, unpublished data). It should be noted however, that the east coast has not received the same amount of attention as the west and south coasts and a recent study from northern KwaZulu Natal reports 204 species of macroinvertebrates found on one species of seagrass alone (Browne et al., 2013). Endemicity of marine species was reported to peak on the south coast, likely an artefact of location, being furthest from neighbouring political boundaries (Griffiths et al., 2010), but in considering coastal range-restricted invertebrates, Griffiths et al. (2010) and Scott et al. (2012) found that endemicity peaked at Cape Point, an area of transition between the west and south-west coasts.

3. Economic worth: past, present, future

3.1. West Coast rock lobster

The 2015 West Coast rock lobster stock assessment estimates the current exploitable biomass (B_{2014}) of West Coast rock lobster at just over 21,700 tonnes (t), almost 3% of the estimated pristine biomass ($B_{pristine}$) and c. 5.8% of B_{MSY}, the biomass that would maximise long-term average catch (i.e. maximum sustainable yield) (Table 3; Johnston, 2015). More recent estimates suggest that the current exploitable biomass is closer to 2% of $B_{pristine}$ (Johnston and Butterworth, 2016b).

Commercial catches peaked in the 1950s, but have since declined (Melville-Smith and Van Sittert, 2005). Since 2005, the total allowable catch (TAC) and actual catch for West Coast rock lobster has ranged from around 2000–3000 t, but in recent years has dropped below 2000 t. The current commercial catch is about 60% less than what it was in the 1980s, and around 30% less than the average catch in the

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Table 3
Estimated pristine ($B_{Pristine}$) and current (B_{2014}) biomasses (tonnes) for West Coast rock lobster and abalone, including biomass required to produce a maximum sustainable yield (B_{MSY}) and current depletion values relative to $B_{Pristine}$ and B_{MSY}. Estimates obtained from Johnston (2015) and Brandão and Butterworth (2015).

Species	Pristine biomass ($B_{pristine}$)	Current biomass (B_{2014})	B_{MSY}	$B_{2014}/B_{pristine}$	B_{2014}/B_{MSY}
West Coast rock lobster	745,429	21,725	372,714.5	0.029	0.058
Abalone	28,936	5084	14,468	0.176	0.351

1990s (Fig. 2a), although there is now a subsistence fishery catching over 200 t each year (Table 4; Fig. 2a). The recreational TAC has been reduced by almost 80% since the 1990s, while the estimated illegal take has increased considerably, based on trends for 2008–2015, and is almost equal to the legal commercial catch (Fig. 2a).

Using the present-day landed value of the resource (c. ZAR 230 or US$ 17.16 per kg; ZAR = the South African Rand, hereafter referred to as R and equivalent to c. US$ 13.4 in May 2017), the current available exploitable biomass of West Coast rock lobster, c. US$ 373 million (R 5 billion), is a fraction of what the estimated 'pristine' and 'sustainable' biomasses would have been worth, c. US$ 12.7 billion (R 170 billion) and US$ 6.4 billion (R 86 billion) respectively (Fig. 2b). In terms of actual catch taken, the current total value of this fishery is US$ 89.3 million year^{-1} (R 1196 million year^{-1}). Broken down into sectors, the value of the commercial, subsistence, recreational and illegal sectors are US$ 27.8 million year^{-1}, US$ 4.0 million year^{-1}, US$ 31.7 million year^{-1} and US$ 25.7 million year^{-1} respectively (Table 5).

In more recent decades, the average amount generated by the commercial rock lobster resource has declined following declines in catches and is currently less than half of what it was in the 1970s (Fig. 2c). Rock lobsters from the recreational sector are not sold, but taking into account value of the resource plus direct and indirect expenditure within the recreational fishery, their economic value is estimated at approximately US$ 31.7 million year^{-1} (R 425 million year^{-1}; Table 5) or US$ 460 (R 6160) per kg. This sector of the fishery has shrunk considerably over the past 10–20 years (Table 6). The number of permits sold has halved since the 1990s and the length of the season has been reduced from 5–8 months during the 1990s, to 3 months and then 0.7 months in more recent years. The value of this recreational fishery is estimated to have declined by approximately US$ 6.7 million year^{-1} over five years between 2005 and 2010 (DAFF, 2012), resulting in this sector having more than halved from US$ 70.5 million year^{-1} to US$ 31.7 million year^{-1}. The illegal fishery is estimated to catch 1500 t of rock lobster year^{-1}, with a landed value of US$ 25.7 million year^{-1} (Table 5). It is concerning that

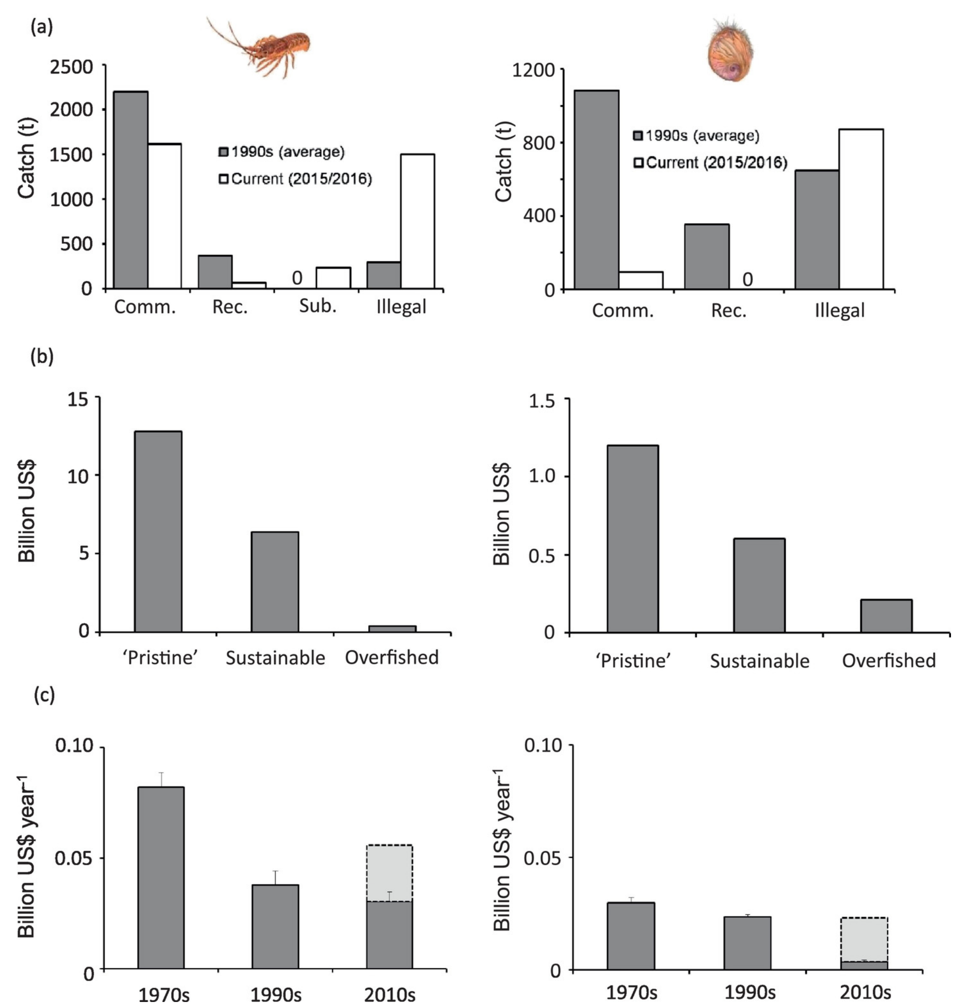

Fig. 2. (a) Current annual catch (tonnes) compared to the average annual catch (tonnes) taken in the 1990s for various sectors of the rock lobster (left panel) and abalone (right panel) fisheries (commercial, recreational, subsistence, illegal); (b) economic value (billions of US$) in terms of the available exploitable lobster (left panel) and abalone (right panel) biomass under pristine (early 1900s), sustainable (B_{MSY}) and overfished (current) conditions; and (c) economic value (billions of US$ year^{-1}) based on mean annual lobster (left panel) and abalone (right panel) catch (+SE) during the 1970s, 1990s, 2010s. The current value of illegally harvested resources is shown for the 2010 period in light shading.

Table 4
Current catch and/or quota (tonnes) per fishery. Linefish not included due to the number of species involved.

Fishing sector	Current catch (2014/2015)	Source	Current quota (2015/2016)	Source
West Coast rock lobster	2160	Statistics SA	1800.85	Data from DAFF
Commercial	1619	Data from DAFF	1496.35	Data from DAFF
Recreational	Data unavailable	–	69.2	Data from DAFF
Subsistence	259.6[a]	Data from DAFF	235.3	Data from DAFF
Illegal	1500	Johnston and Butterworth (2016a)	0	–
Abalone				
Commercial	55[a]	Statistics SA	96	Data from DAFF
Recreational	0	–	0	–
Illegal	875	Brandão and Butterworth (2015)	0	–
Kelp				
Dry beach cast	389.2	Data from DAFF	Data unavailable	–
Fresh beach cast	249	Data from DAFF	Data unavailable	–
Harvest (aquafeed)	3974.1	Data from DAFF	Data unavailable	–
Harvest (fertilizer)	1930.6	Data from DAFF	Data unavailable	–
Other seaweeds	0	Data from DAFF	0	–

[a] Data shown for previous year.

almost US$ 60 million worth of rock lobster per year (value of commercial + illegal catch) is being removed from the total exploitable population, estimated to be worth c. US$ 373 million (Fig. 2). If the illegal sector cannot be contained and scientific recommendations on stock recovery continue to be ignored, the resource will continue to decline.

3.2. Abalone

The exploitable abalone biomass is estimated at just over 5000 t, approximately 17.5% of $B_{pristine}$ and 35% of B_{MSY} (Table 3; Brandão and Butterworth, 2015). Catches peaked in the 1960s, but declined with the introduction of fishing regulations in the 1970s, and then remained stable up until the mid-1990s (Raemaekers et al., 2011). Changes to the ecosystem and rampant illegal fishing resulted in reduced TACs from the 2000s. In recent years, catches have been under 200 t and the current commercial catch is approximately one tenth of what it was in the 1990s (Fig. 2a). The recreational fishery accounted for, on average, almost 400 t year^{-1} in the 1990s, dropping to 42.5 t in 2001/02 (Raemaekers et al., 2011) and then closed in 2003 (Fig. 2a; Table 4). The illegal sector expanded in the 1990s with an average catch of over 600 t, but is currently estimated to be over 800 t (Table 4; Fig. 2a).

Using the present-day landed value of the resource (c. R 556 or US$ 41.5 per kg), the current available abalone biomass is currently worth c. US$ 210 million (R 2.8 billion) compared to approximately US$ 600 million (R 8 billion) if fished sustainably (B_{MSY}), and US$ 1.2 billion (R 16 billion) prior to commercial fishing ($B_{Pristine}$, Fig. 2b). With respect to actual catches taken, the current total value of the abalone fishery is US$ 22.6 million year^{-1} (R 303 million year^{-1}), although only 13.5% of this is considered legal, with the commercial fishery currently estimated at US$ 3.0 million year^{-1} (Table 5; Fig. 2c), which is less than half of what it was in the 1990s and 1970s (Fig. 2c). Although the recreational fishery no longer exists, it had a TAC of 42.5 t before closing (Raemaekers et al., 2011) and was estimated at US$ 1.7 million year^{-1} (R 23 million year^{-1} based on Turpie et al., 2003; Table 5). Taking in to account the actual value of the resource itself (R 308 or US$ 23 per kg at the time; Raemaekers et al., 2011), the worth of the recreational sector was c.

Table 5
Current Value (million US$ and million Rand (R) year^{-1}) for direct and indirect ecosystem services associated with South African kelp forest and temperate reef ecosystems.

Ecosystem service	Current value		Source
	(Million US$ year^{-1})	(Million R year^{-1})	
West Coast rock lobster fishery			
Commercial	27.79	372.40	Estimated (see text)
Recreational	31.72	425.05	Estimated from DAFF (2012)
Subsistence	4.04	54.10	Estimated (see text)
Illegal	25.75	345.00	Estimated (see text)
Abalone fishery			
Commercial	3.06	41.00	DAFF (2014)
Recreational	–	–	–
Illegal	19.55	262.00	Estimated (see text)
Linefish fishery			
Commercial	10.09	135.22	Estimated (data from DAFF)
Recreational	51.96	696.25	Leibold and Van Zyl (2008)
Spearfishing	0.97	13.00	Leibold and Van Zyl (2008)
Kelp fishery			
Collection (alginate)	0.03	0.42	Estimated (see text)
Harvest (aquafeed)	0.59	7.95	Estimated (see text)
Harvest (fertilizer)	0.29	3.86	Estimated (see text)
Other seaweeds	0.00	0.00	
Bait items	1.46	19.65	Turpie et al. (2003)
Ecotourism	113.06	1515.00	Estimated from DEA (2014)
Nutrient recycling	144.00	1937.00	Estimated (see text)
Research	0.07	0.97	LKB and JJB grants
Total	434.4	5828.90	

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Table 6
Permits sold ('000 year^{-1}), season length (months) and value (million US$ and million Rand (R) year^{-1}) of the rock lobster and abalone recreational fisheries, past (1990s/2000s) vs. present (2010s).

Recreational fishery	Permits sold	Season length	Value	
	('000 year^{-1})	(Months)	(Million US$ year^{-1})	(Million R year^{-1})
West Coast rock lobster				
1990s/2000s	>50,000	5–8	70.5	944
2010s	26,000	0.7–3	31.7	425
Abalone				
1990s/2000s	17,000–30,000	4–9	1.7	23
2010s	0	0	0	0

US$ 2.7 million year^{-1} or US$ 63.2 (R 847) per kg. In the 1990s and early 2000s, the number of permits sold ranged from 17,000–30,000 and the fishing season ranged from 4–9 months (Table 6). The street value for illegally caught, dried abalone was approximately R 3000 (US$ 224) per kg in 2013 (Goga, 2014). Given that dried abalone shrinks to about one tenth of its mass (Steinberg, 2005), the current illegal catch, c. 875 t, has an estimated street value of US$ 19.5 million year^{-1} (Table 5) almost equivalent to the commercial value of the resource in the 1990s (Fig. 2c). As with the West Coast rock lobster fishery, the future of this resource depends on curbing illegal fishing and implementing stock recovery plans recommended by scientists. In an attempt to meet global demands, land-based abalone mariculture has been operating successfully since the mid-1990s and two abalone ranching (sea-based) operations began in 2013.

3.3. Linefish

Increased exploitation of linefish during the second half of the 1900s meant that by the year 2000 many stocks were considered overfished or collapsed (Griffiths, 2000). The recent implementation of new and improved stock assessment methods (e.g. Winker et al., 2013) has shown that reduced fishing effort in the 2000s allowed some stocks, such as Hottentot *Pachymetopon blochii* and Carpenter *Argyrozona argyrozona*, to recover (DAFF, 2014). However, other species are slow to recover e.g. Silver kob *Argyrosomus inodorus* or are likely to rely on the benefits of Marine Protected Areas for stock recovery e.g. reef sparids (DAFF, 2014; Kerwath et al., 2008, 2013). Many species still remain overfished or susceptible to overfishing (Table 2).

In 2013 the South African commercial linefishery was valued at US$ 10.6 million year^{-1} (R 142.34 million year^{-1}; DAFF unpublished data). Approximately 95% of this catch is taken along the west and south coasts, thus valuing the commercial linefishery in the southern Benguela at c. US$ 10.1 million year^{-1} (Table 5). Based on an economic assessment of recreational angling in 2007 by Leibold and Van Zyl (2008), the nearshore recreational fishing industry (light tackle boat, surf, shore) and spearfishing industry had an estimated total value of US$ 207.5 million year^{-1} and US$ 3.9 million year^{-1} respectively. Assuming that 25–30% of this fishing occurs in the Western Cape (C. Attwood, University of Cape Town, pers. comm.), the value for the southern Benguela region is therefore c. US$ 51.9 million year^{-1} for the boat/shore recreational linefishery and US$ 0.97 million year^{-1} for the recreational spearfishing industry (Table 5). These values are similar to those reported by Turpie et al. (2003): US$ 51.2 million year^{-1} (R 686 million year^{-1}) for recreational boat and shore angling, and US$ 1.4 million year^{-1} (R 19 million year^{-1}) for the spearfishing industry. Recreational catch is not permitted to be sold and there is no information on the estimated value of the landed species by the recreational fishery. The total value for the linefishery (all sectors) in the southern Benguela region is approximately US$ 63 million year^{-1} (R 844.5 million year^{-1}), while the entire South African linefishery sector is valued at well over US$ 149 million year^{-1} (R 2 billion year^{-1}). Recent improvements in stock assessment methods and the recovery of some stocks are promising, but many remain overexploited or unknown and demands on resources remain high.

3.4. Seaweeds

Most of the South African seaweed industry is based on various uses of kelp (mostly *E. maxima* with some *L. pallida*) on the west and southwest coasts (Anderson et al., 2003). The only major exception is the harvesting of the red seaweed *Gelidium* in the Eastern Cape, which is collected intertidally by hand, dried and sold overseas for agar extraction. The *Gelidium* harvest has been consistently c. 100 dry t year^{-1} for many years. Although small, this is significant, with a global shortage of seaweed for agar as commercial aquaculture of *Gelidium* has thus far not been successful anywhere. In the past, large amounts of *Gracilaria* were collected as washup in Saldanha Bay and similarly dried and exported for agar production. This was over 1000 dry t year^{-1} in the 1960s, but ceased to be commercial in the 1970s, probably due to the major construction in the Bay affecting the ecology (Rothman et al., 2009). Small amounts have been collected since, but none since 2007.

Kelp has been collected as washup for many years, dried and exported for alginate production. The amounts vary, linked with the world alginate market which has been static for a number of years; the maximum was c. 5000 dry t in 1977, but since 2000 the average has been just over 700 dry t year^{-1} and the most recent collection (2015/16) was 389.2 dry tonnes (Table 4). Fresh kelp is also harvested directly from kelp forests, an amount that has varied between 3000 t and almost 8000 t since 2000, with recent harvests fluctuating around 6000 t (DAFF, 2014). These fresh harvests are used for two different purposes. Since the rise of the abalone aquaculture industry in the mid-1990s, kelp has been harvested directly to be fed fresh as abalone feed with an average of 4500 fresh t year^{-1} since 2000 and a maximum of over 6000 fresh t year^{-1} in 2011. The most recent harvest was just under 4000 fresh t year^{-1} (Table 4). A little fresh kelp washup has also been collected for abalone feed, with the most recent amount c. 250 fresh t year^{-1} (average since 2000, 280 fresh t year^{-1}, maximum 1866 fresh t in 2003). Fresh harvested kelp has also been used by Kelp Products International, since the 1970s, to extract a liquid agricultural growth stimulant (various products including Kelpak®). The current harvest (*E. maxima*) for this is almost 2000 fresh t year^{-1} (Table 4).

A tonne of dry *Ecklonia* produces c. 250 kg of alginate, currently worth c. US$ 320 per tonne (B. Rudolph, CP Kelco, pers. comm.). Thus, 390 dry t year^{-1} for alginate would produce alginate worth c. US$ 31,200. Fresh kelp for abalone feed is valued at R 2000 or US$ 149 per tonne and thus this sector is estimated at c. US$ 0.59 million year^{-1} (Table 5). Assuming fresh kelp for agricultural growth stimulant e.g. Kelpak® might also trade at US$ 149 per tonne, the value of the natural resource for this sector is c. US$ 0.29 million year^{-1} (Table 5), however, this does not take into account added value when this kelp is converted into an agricultural growth stimulant. The total value of the seaweed industry is at least US$ 0.9 million year^{-1}, excluding added values to the resource. Given that kelps in particular are well managed and underexploited in some areas, there is potential for expansion in this sector in

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the future, although ecosystem effects of large scale harvesting need to be monitored (Anderson et al., 2006).

3.5. Bait

Bait items, including red bait, polychaete worms, abalone, bivalves, squid, rock lobster and crabs, harvested by shore-anglers on the west and south coasts were valued at c. R 19.65 million year^{-1} or US$ 1.5 million year^{-1} (Table 5) in the early 2000s (Turpie et al., 2003).

3.6. Ecotourism

There is little published information on the value of marine-based ecotourism for the southern Benguela region. A study by Hara et al. (2003) on tourism in the Gansbaai region reported that shark-cage diving turned over US$ 2.1 million year^{-1}; boat-based whale watching US$ 238,000 year^{-1}; and other marine-based activities including Dyer Island boat trips, generated over US$ 29,800 year^{-1}. These values do not include recreational fishing or land-based marine tourism (e.g. beaches, whale watching from shore, fishing), nor do they take into account money spent on accommodation, food and retail. Whale watching in Hermanus was valued at R 7.3 million year^{-1} or US$ 0.54 million year^{-1} in the mid-1990s (Findlay, 1997). Turpie et al. (2003) estimated that approximately R 131 million year^{-1} (US$ 9.8 million year^{-1}) was generated from ecotourism in the Western Cape, which included shark-cage diving, whale watching, SCUBA diving, but also land-based ecotourism such as bird watching and botanical appreciation. More recent values of this sector can be found in the DEA (2014) report, where using US$ 1 = R 13.4, whale watching (land and boat based) is estimated to generate US$ 7.5 million year^{-1}, shark-cage diving US$ 6.9 million year^{-1}, seal tourism US$ 370,000, seabird tourism US$ 1.8 million year^{-1}, SCUBA diving US$ 4.5 million year^{-1}, and eco filming US$ 9.0 million year^{-1}. Assuming that approximately a third of SCUBA diving and half of the eco filming occurs in the southern Benguela, ecotourism is estimated to directly generate just over US$ 22.4 million year^{-1} with an overall value to the economy of US$ 113 million year^{-1} (Table 5), assuming an approximate multiplier of five (DEA, 2014). Under careful management, there is scope for the ecotourism sector to expand, and the potential for local communities to get involved.

3.7. Indirect services

As Bennett et al. (2016) point out, ecological economists highlight the major importance of ecosystem services contributed by temperate reefs. In particular, the majority of the value calculated for these reefs by Costanza et al. (1997) consists of a figure for nutrient recycling. Based on values from Costanza et al. (1997), Bennett et al. (2016) calculated that the c. 7 million ha of 'Great Southern Reef' around most of Australia, on reefs shallower than 30 m where seaweeds dominate, equates to "as much as AU$ 187 billion year^{-1} of nutrient cycling services that are critical to human welfare but currently do not feature in Australia's gross domestic product (GDP)". Anderson et al. (2007) calculated the total area with 'surface kelp' on the South African coastline to be c. 5000 ha. Using more recent values from Costanza et al. (2014) (1 ha of reef area equivalent to US$ 28,916 year^{-1}), this would give the reef with surface kelp in South Africa a value of US$ 144 million per year^{-1} for nutrient recycling alone. This would be a conservative figure, as there is estimated to be an equivalent area with subsurface kelp (RJ Anderson, DAFF, pers. comm.). Given South African surface kelp forests are estimated to cover an area of c. 5000 ha (Anderson et al., 2007) and based on an *E. maxima* C fixation rate of 0.002 t C m^{-2} year^{-1} (Mann et al., 1979), approximately 102,500 t of C are fixed by these kelp forests each year. Accounting for subsurface forests and beds of understory seaweeds will likely double this value. However, they do not contribute to long-term C storage or mitigate against climate change because they do not have below-ground C storage capacity and their turnover is very rapid, with most of their productivity probably being remineralised. Nonetheless, they may play an indirect but significant role in carbon sequestration by acting as carbon donors to recipient Blue Carbon habitats (e.g. seagrass meadows, deep sea sediments), some of which may be stored in marine ecosystems for timescales relevant for sequestration (Fourqurean et al., 2012).

Universities actively involved in research relating to kelp forest ecosystems include University of Cape Town and University of the Western Cape with research grants from the National Research Foundation that have averaged almost US$ 73,000 year^{-1} from 2014–2016 (Table 5).

In total, the current value of this ecosystem is estimated at US$ 434 million year^{-1} (R 5.8 billion year^{-1}), of which US$ 290 million year^{-1} (R 3.9 billion year^{-1}) contributes to the South African GDP, with ecotourism contributing almost 40% of this, followed by recreational fishing (28%), and commercial and illegal fishing (c. 15–16% each). Indirect ecosystem services such as nutrient cycling are valued at US$ 144 million year^{-1} (R 1.9 billion year^{-1}), but aren't realised in the country's GDP given they do not provide direct economic value.

4. Future research directions and synthesis

Since the Kelp Bed Ecology Programme of the 1970s and 1980s, there has been no concentrated research effort afforded to South African kelp ecosystems. While there have undoubtedly been some important findings related to species within these systems (see Branch, 2008 for a review), the number of published, peer-reviewed papers from South Africa during the 2000s (c. 10) is extremely low in comparison to Australia, USA (both at c. 100), New Zealand, Chile, Norway (c. 40 for each) and Canada (c. 30; see Smale et al., 2013). Indeed this may reflect research capacity across the regions, but it is also likely a product of greater interest and funding directed to offshore ecosystems and associated fisheries in the southern Benguela. Future research directions are likely to be centred around the impacts of climate change, overfishing and invasive species on kelp forest ecosystems.

The ecosystem effects of overfishing marine systems, including kelp ecosystems, has received considerable attention (e.g. Jackson et al., 2001; Ling et al., 2009; Scheffer et al., 2005; Steneck et al., 2004; Tegner and Dayton, 2000). In South Africa, key coastal resources including rock lobster, abalone and various species of linefish are overfished but little research effort has been afforded to understanding the ecosystem effects of this overfishing (although see Blamey et al., 2014). In particular, *J. lalandii* is a significant predator on benthic reefs (Barkai and Branch, 1988; Blamey and Branch, 2012) and substantial population declines along the west coast (biomass estimated to be 2–3% of pre-exploitation biomass) are likely to have impacted the rest of the ecosystem; however, these impacts remain largely unknown.

The effects of climate change on kelp ecosystems has been a focus across the globe in recent years (e.g. Krumhansl et al., 2014; Provost et al., 2017; Simonson et al., 2015a, 2015b; Smale and Vance, 2016; Vergés et al., 2014; Wernberg et al., 2010, 2013, 2016), particularly in global warming hotspots. Krumhansl et al. (2016) report that 65% of global ecoregions are experiencing changes (increase or decrease) in kelps, although these changes vary spatially, in part due to different regional drivers. In South Africa, coastal waters have cooled in the southern region of the southern Benguela (Blamey et al., 2015; Rouault et al., 2010) and *E. maxima* has extended its range along the south coast since the mid-2000s (Bolton et al., 2012) and become more abundant within its range along the south-west coast (Reimers et al., 2014).

The West Coast rock lobster has also shifted eastwards, likely due to environmental conditions (Cockcroft et al., 2008), with significant ramifications on reef biota, including a decline in grazers and an associated increase in kelps and other seaweeds (Blamey et al., 2010; Blamey and Branch, 2012). There is a need for further research to better understand (1) the ecological effects of these changes in a system already under pressure, (2) their effects on major resources and (3) the socio-economic adaptations available for low-income fishing communities whose livelihoods depend on a number of these coastal species.

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In contrast, ocean warming has been observed in the northern Benguela and is thought to extend into the northern part of the southern Benguela (Blamey et al., 2015; Jarre et al., 2015). However; there is little data available for kelp ecosystems north of Saldanha Bay, a more remote region of the west coast, given that much of the research on South African kelp ecosystems has focused on the more accessible regions in the south. Thus there is also a need for increased capacity in the north, but also base-line surveys followed by longer-term monitoring projects.

Non-native species can have serious consequences on native species and their ecosystems (Grosholz, 2002), and this has been shown for temperate reef systems elsewhere in the world (Casas et al., 2004; Lambert et al., 1992; Levin et al., 2002). The study of marine invasions in South Africa is fairly new, beginning in earnest in the 1990s (Griffiths et al., 2009). Much of the work done since comes from rocky intertidal shores, with <10% from the subtidal (Alexander et al., 2016). A greater focus on the subtidal is needed, especially in ecosystems with weakened resilience due to e.g. overfishing.

In conclusion, South African kelp forest and temperate reef ecosystems are worth US$ 434 million $year^{-1}$ (R 5.8 billion $year^{-1}$) and although only US$ 290 million $year^{-1}$ (R 3.9 billion $year^{-1}$) features in the GDP, this value still exceeds two of South Africa's most valuable offshore fisheries: the demersal trawl fishery, valued (in 2013) at US$ 268 million $year^{-1}$ (R 3.6 billion $year^{-1}$) and the pelagic fishery valued at US$ 119 million $year^{-1}$ (R 1.6 billion $year^{-1}$; DAFF, unpublished data). The contribution to the gross state product (GSP) is, however, low (c. 1%). Ecotourism brings in a large amount of revenue and, given proper management, there is scope for expansion in this sector. Recreational fisheries, even after serious reductions in TAC over the last twenty years, bring in the bulk of the revenue from the fishing sector and have an exceptionally high value per kg, but subsistence fishers are the ones most reliant on the resource. Striking a balance between these sectors is undoubtedly challenging, and will require careful planning and management, with an increased focus on interdisciplinary projects looking at socio-economic adaptations for local fishing communities. While much of the overall worth of these temperate coastal systems is from the direct ecosystem services provided, the indirect services are considered equally important, particularly in a time of increased urbanisation and climate change. South African kelps are not in trouble – they are expanding, and kelp harvesting is well-managed – but some of the resources within kelp ecosystems, are a different matter. The future of both the abalone and rock lobster resources is grim: government is still unable to curb the ongoing and often blatant illegal fishing in the abalone sector, and the increased illegal fishing of West Coast rock lobster, an already overfished resource, has reached a crisis.

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