Reference points for predators will progress ecosystem-based management of fisheries.

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SUPPORTING INFORMATION

Case studies and detailed scores

Case study 1: Common cockle and oystercatcher in Burry inlet (UK)

Table S1. Summary of *Common cockle and oystercatcher in Burry inlet* case study, including location; spatial scale; fished species; catch and biomass in tonnes with catch as a percentage of assessed biomass (C/B) in brackets; institutional scale of management (N – national , I – international) and MSC status; representative predator species; and their IUCN red list status (LC – least concern, NT - near threatened, VU - vulnerable, EN – endangered, i – increasing, d – decreasing, s – stable, u - unknown).

Location	Scale (km^2)	Fished species	Catch (t), Biomass (t), (C/B)	Management	Predators	Red list
Burry Inlet, Wales, UK (Northeast Atlantic)	66	Common cockle, *Cerastoderma edule*	1,191 12,313 (10%)	National (UK) MSC certified	Eurasian oystercatcher, *Haematopus ostralegus*	NT, d

NOTES: The catch estimate is for 2017 season and the biomass estimate is for October 2017 (NRW data; Smith 2018).

Coastal habitats are important sites for shellfish, such as the common cockle (*Cerastoderma edule*) and mussel (*Mytilus edulis*), many supporting commercial shellfisheries of high economic value within Europe. Shellfish are also the primary food for some internationally-protected bird species, including oystercatcher (*Haematopus ostralegus*) and red knot (*Calidris canutus*). Shellfishing has several effects on these birds, some negative, but some positive (Stillman & Goss-Custard 2010). Shellfishing removes the larger shellfish eaten by birds such as oystercatcher. If shellfishing occurs at low tide when shorebirds are feeding, it can exclude them from preferred habitats. In contrast, when artificial intertidal shellfish beds are created, the amount of food for the birds can be increased.

Coastal and estuarine shellfisheries occur throughout Europe and tend to be managed at local scales (e.g., within specific estuaries) and employ different methods. The current case study focuses on the methods used to manage the cockle fishery in the Burry

Inlet (UK), which is also an important, and protected, overwintering site for wading birds. Similar methods are used to manage other UK shellfisheries including in the Wash and Dee Estuary.

Shellfish stock sizes are measured for shellfishery management, for example as biomass over a minimum fishable size, within identified beds. In the Burry Inlet biomass assessments occur biannually, in spring and autumn, as management depends on year-to-year variation in size of shellfish stocks relative to requirements of the birds.

The sizes of European coastal bird populations are relatively well known from monitoring schemes. Within the UK the Wetland Bird Survey (WeBS) occurs throughout the shorebird overwintering period and estimates monthly population sizes at all important sites (https://www.bto.org/volunteer-surveys/webs). The shellfish food reserves of the birds can usually be derived from shellfishery surveys, but the abundance of other foods, such as marine worms, which can be vital when shellfish are rare, are less well known, and usually derived from bespoke surveys to estimate overall site condition.

The overall aim of shellfishery management is to set a Total Allowable Catch (TAC) that allows exploitation of the shellfish stocks, while not adversely affecting future shellfish recruitment, and reserving sufficient food for the birds. The birds require enough food so that their survival rates are not decreased and so that they have sufficient fat stores for migration to the breeding grounds and successful breeding (Smit *et al.* 1998). The process of calculating TACs, and how this depends on underlying shellfish and bird data, has varied through time and between sites.

Calculating the food requirements of bird populations can be a complex task, and has traditionally been beyond the scope of shellfishery management organisations. However, developments in the understanding of shellfish-feeding birds (e.g. Goss-Custard *et al.* 2004; Stillman *et al.* 2016) have allowed a simple, but scientifically-informed, approach that can be applied on a year-on-year basis as shellfish stocks and bird populations change size. This accounts for the amount of food birds need in the environment at the start of winter (the Ecological Requirement) to allow them to find enough to survive in good condition to the end of winter (the Physiological Requirement). The ecological requirement is calculated from the physiological requirement by:

$$Ecological\ Requirement = Physiological\ Requirement \times Ecological\ Multiplier$$

The TAC is ultimately calculated as a function of both *Shellfish biomass* and the *Ecological Requirement* of dependent seabirds.

The Ecological Multiplier can range between 2 and 8 for oystercatcher, depending on sites and whether the shellfish species is cockle or mussel (Goss-Custard *et al.* 2004). The Ecological Requirement can greatly exceed the Physiological Requirement as resource competition may exclude some birds from the most profitable food, birds cannot find all of the food, and food may be lost due to other causes (Goss-Custard *et al.* 2004). In the UK this approach is used in the management of estuaries including the Wash, Dee Estuary, and Burry Inlet. These fisheries can be closed or opened, and TACs set, on the basis of the food requirements of the birds and total shellfish stock. The Burry Inlet is legally designated to support 13,590 oystercatchers, equivalent to the mean peak population size between 1991/92 and 1995 /96. TACs for the cockle fishery are based on this target oystercatcher population size and an Ecological Multiplier of 2 (Stillman *et al.* 2010, MSC 2017). This translates into a fixed requirement to ensure that a minimum 4,800t of cockles is available for oystercatchers at 1st September or other available food sources. Oystercatchers also feed on alternative prey such as mussels.

The process for allocating the shellfish biomass between the requirements of birds, future recruitment and TAC is hierarchical. The first consideration is to reserve sufficient biomass at the start of winter to meet the food requirements of oystercatchers. The uneaten portion of the bird allocation is also intended to reserve sufficient cockle biomass to support cockle recruitment in the spring and summer. Thus the 4,800t bird allocation is also a reference point for cockles. The fishery opens with a TAC for April and May calculated from the autumn survey biomass minus the winter TAC, the bird allocation and assumed overwinter cockle mortality. TACs for the remaining summer months are based on the spring survey biomass, adjusted to account for catch and natural mortality (estimated from small scale monthly surveys from June to September). The autumn survey updates the biomass estimate, and TACs for the winter months are based on any biomass above the bird allocation, with adjustments for catch and natural mortality. The fishery will be closed if there is insufficient biomass above the bird allocation to support it. This approach includes additional precaution as cockles below the minimum landing size are excluded from the TAC calculations. Red knot also have a substantial requirement for cockles in Burry inlet, but they feed on small cockles below the minimum landing size. Actual harvests are further limited by strict effort controls including a maximum number of harvesting permits and individual daily quotas. Compliance is rated as "generally good" (MSC 2017).

Although the bird allocation is currently fixed, the process and supporting legislation could accommodate new allocation estimates based on revised consumption models or a revised reference point for the bird population. Any proposed revisions would require careful evaluation to assess whether the assumption that the uneaten portion of the bird allocation is sufficient to support cockle recruitment remains valid.

The danger of underestimating the shellfish food requirements of birds has been clearly highlighted in the Netherlands. A policy to ensure that 60% of the food requirements of the birds remained each year after harvesting (i.e. Ecological Multiplier = 0.6), incorrectly assuming the remainder to be provided by alternative prey (Smit *et al.* 1998), led to large bird population declines and has now changed to allow more shellfish to be reserved for them. Similarly, high mortality rates of oystercatcher were observed in the Wash when shellfish stocks were exceptionally low (Atkinson *et al.* 2010).

Sustainable shellfishery management relies on accurately assessing the amount of shellfish that needs to be reserved in the environment to support the birds – i.e. the size of the Ecological Requirement. The large declines of shellfish-feeding birds in The Netherlands highlight the potential danger for the birds when food requirements are underestimated. The danger of overestimating food requirements is the potential loss of economic income that could result. A key future priority is to accurately predict the size of the Ecological Multiplier, taking account of between-site variation in shellfish species, size and abundance (Stillman *et al.* 2016).

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Table S2. Scores for the *Common cockle and oystercatcher in Burry inlet (UK)* case study. A score of 1 indicates the presence of the relevant component of a target species feedback loop (Fig 1) designed to achieve objectives for the fished stock or the extra components of an predator feedback loop intended to achieve additional objectives for predators of the fished stock. The evidence to support each score is a verbatim quote from the case study.

	Target species feedback loop (objectives for common cockle and fishery)		**Predator feedback loop (additional objectives for Eurasian oystercatcher)**	
Component	Score	Evidence	Score	Evidence
Variable	1	TAC is calculated as a function of both *Shellfish biomass* and the *Ecological Requirement*	1	The Burry Inlet is legally designated to support 13,590 oystercatchers
Data	1	biomass assessments occur biannually, in spring and autumn	1	the Wetland Bird Survey (WeBS) occurs throughout the shorebird overwintering period and estimates monthly population sizes
Estimate	1	biomass assessments occur biannually, in spring and autumn	1	the Wetland Bird Survey (WeBS) occurs throughout the shorebird overwintering period and estimates monthly population sizes
Reference point	1	the 4,800t bird allocation is also a reference point for cockles	1	TACs for the cockle fishery are based on this target oystercatcher population size
Adjustment method	1	TAC is calculated as a function of both *Shellfish biomass* and the *Ecological Requirement*	0	the bird allocation is currently fixed
Implementation	1	Actual harvests are further limited by strict effort controls including a maximum number of harvesting permits and individual daily quotas. Compliance is rated as "generally good"		*NA*
Total score	6		4	

Case study 2: South African sardine and African penguin in South African waters.

Table S3. Summary of *South African sardine and African penguin in South African waters* case study. Further details as Table S1.

Location	Scale (km^2)	Fished species	Catch (t), Biomass (t), (C/B)	Management	Predators	Red list
Western Cape (Southeast Atlantic)	500,000	Sardine (South African sardine), *Sardinops sagax ocellatus*	45,560 335,000 (13.6%)	National (South Africa) Not MSC certified	African penguin *Spheniscus demersus*	EN, d

NOTES: Catch and biomass estimate are for 2017 (Coetzee *et al.* 2017, Oceana 2017).

Case study

South African sardine, also known as sardine, *Sardinops sagax* is a small, short-lived, fast growing and early-maturing epipelagic fish species found in shelf waters off most of South Africa's coast (Beckley and van der Lingen 1999). Sardines are highly sensitive to environmental forcing and show large changes in population size (Checkley *et al.* 2009). Biomass estimates off South Africa have ranged from <100 000 to >4 million tonnes over the period 1984-2016, although they have been at low levels since 2005 as a result of sustained poor recruitment (Coetzee *et al.* 2016). This low biomass, together with an eastward shift in the relative distributions of sardines and anchovies *Engraulis encrasicolus*, has had significant consequences for the food web (Blamey *et al.* 2015). Sardines are the dominant prey of a suite of marine top predators, including seabirds such as the endangered African penguin *Spheniscus demersus*, endangered Cape cormorant *Phalacrocorax capensis* and endangered Cape gannet *Morus capensis* (Crawford *et al.* 2015). Sardines are also targeted by a purse-seine fishery, managed by the Fisheries Management Branch (FMB) of the Department of Agriculture, Forestry and Fisheries (DAFF), that has caught ca 130 000 tonnes per year since 1950 (van der Lingen *et al.* 2015). The legal foundation for the management of South African fisheries is the Marine Living Resources Act, 1998 (Act No. 18, 1998) of South Africa, which recognises "the need to protect the ecosystem as a whole, including species which are not targeted for exploitation".

Sardine population size has been estimated since 1984 using bi-annual hydro-acoustic surveys that cover shelf waters off most of South Africa (de Moor *et al.* 2008). Those data, together with length-frequency data from commercial catch samples, are used to develop assessment models of the sardine population (e.g. de Moor and Butterworth 2015), which are then integrated in an adaptive Operational Management Procedure (OMP) (DAFF 2014). The present OMP (OMP-14; de Moor and Butterworth 2014) sets "Initial" TACs at the start of each year in response to the stock assessment following the November survey. It revises these to "Final" TACs following the mid-year recruitment survey. The OMP was chosen because simulations suggest it has a low probability that the abundance of sardines will fall below pre-agreed thresholds at which future recruitment might be compromised. In order to maintain stability in the fishery it is also subject to constraints on the extent to which TACs can vary from year to year. OMP-14 implies a maximum probability of 0.21 that total biomass of age 1+ sardines will fall below 700 000t at least once during 20 year projections. The OMP generally sets TAC at 8.7% of 1+ sardine biomass, but it also responds to the availability of anchovies and to "Exceptional Circumstances" population levels (as observed in the survey of total biomass in the previous year; 300 000 tonnes for sardines) below which the TACs are rapidly reduced, and a "buffer zone" of between 300 000 and 600 000 tonnes where a conservative "Initial directed sardine TAC" is set. The OMP-recommended catch allowances are allocated to individual Right Holders in the sardine fishery who are issued annual permits to catch their allocations. The DAFF is considered effective at implementing catch control measures; catch allowances are adhered to and have not been exceeded for the past 30 years (Coetzee *et al.* 2008, DAFF 2014).

Annual estimates of all seabird and seal colonies size have been made by the Department of Environmental Affairs around South Africa since the early 1980s, with additional diet sampling or breeding success monitored on a subset of colonies, including Robben Island on the West Coast of South Africa (e.g. Crawford *et al.* 2006, Cohen *et al.* 2014). Following a 70% decrease in penguin numbers since the early 2000s (Crawford *et al.* 2011), an African Penguin-Biodiversity Management Plan was gazetted in 2013 in terms of the National Environmental Management: Biodiversity Act (Act No. 10 of 2004). Its vision was to (1) halt the decline of the penguin population in South Africa by 2015; (2) thereafter, contribute to increasing the population by at least 1% growth per year to a minimum of 35 000 breeding pairs; and (3) remove the African penguin from the IUCN threatened categories within one human generation (30 years) from the implementation of the plan (DEA, 2013).

Management of the sardine fishery does not currently incorporate the national objectives for African penguins and no modification of fishing activities is currently planned in response to observed changes in African penguin numbers. The OMP-14 includes a population dynamics model of African penguins on one island breeding colony (Robben Island) which was selected on the basis of data quality and colony size (in 2011, it included 8.9% of all breeding pairs in South Africa). In the model, penguin dynamics are coupled to projected sardine biomass trajectories under two contrasting scenarios of sardine distribution (de Moor and Butterworth 2014). The model is conditioned on past dynamics of the colony. However, the current penguin colony size is not taken into account in setting TACs. It was used in the evaluation of the current OMP through simulation. The OMP gives total catch levels (for the whole area open to fishing) which are deemed acceptable in terms of their simulated impacts on Robben Island penguins, particularly as sardine distribution is estimated to have large impact on adult penguin survival there (Robinson *et al.* 2015) and because assessment models estimate relatively low (10%) fishing mortality compared to sardine natural mortality (de Moor and Butterworth 2016). There are no current spatial management plans for the fishery although these are under consideration (e.g. de Moor 2017).

An "Island Closure" experiment was initiated in 2008 by DAFF with the participation of seabird biologists and fishery representatives, to explore whether excluding purse-seine fishing around some penguin colonies could benefit them. Since then, data on penguin breeding success, foraging effort and chick growth during open and closed periods have been collected (e.g. Pichegru *et al.* 2010, Sherley *et al.* 2015) and used in models to evaluate the effect of closure on penguin demographics, but different models have generated contradictory conclusions (e.g. Hagen *et al.* 2014, Robinson *et al.* 2015, Sherley 2016, Ross-Gillespie and Butterworth 2016, see Dunn *et al.* 2017). Given this, none of the model outcomes produced so far for this experiment have been taken into account in management of the small pelagic fishery and the island closure experiment is continuing, while penguin numbers on the West Coast continue to decrease (A. Makhado and R. Crawford, DEA, unpubl.).

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Table S4. Scores for the *South African sardine and African penguin in South African waters* case study. A score of 1 indicates the presence of the relevant component of a feedback loop. Further details as Table S2.

	Target species feedback loop (objectives for South African sardine and fishery)		**Predator feedback loop (additional objectives for African penguin)**	
Component	Score	Evidence	Score	Evidence
Variable	1	total sardine 1+ biomass	1	OMP-14 includes a population dynamics model of African penguins on one island breeding colony (Robben Island)
Data	1	Sardine population size has been estimated since 1984 using bi-annual hydro-acoustic surveys … together with length frequency data from commercial catch samples	1	Annual estimates of all seabird and seal colonies size have been made by the Department of Environmental Affairs around South Africa since the early 1980s, with additional diet sampling or breeding success monitored on a subset of colonies, including Robben Island
Estimate	1	… used to develop assessment models of the sardine population	1	Annual estimates of all seabird and seal colonies size
Reference point	1	a low probability that the abundance of sardines will fall below pre-agreed thresholds	0	Management of the sardine fishery does not currently incorporate the national objectives for African penguins
Adjustment method	1	The present OMP sets “Initial” TACs at the start of each year in response to the stock assessment	0	no modification of fishing activities is currently planned in response to changes in African penguin numbers.
Implementation	1	DAFF is considered effective at implementing catch control measures.		*NA*
Total score	6		3	

Case study 3: Antarctic krill and its predators in the Southwest Atlantic sector of the Southern Ocean

Table S5. Summary of *Antarctic krill and its predators in the Southwest Atlantic sector of the Southern Ocean* case study. Further details as Table S1.

Location	Scale (km^2)	Fished species	Catch (t), Biomass (t), (C/B)	Management	Predators	Red list
Scotia Sea & West Antarctic Peninsula (Southern Ocean)	3,500,000	Antarctic krill, *Euphausia superba*	236,939 60,300,000 (0.4%)	International (CCAMLR) MSC certified operator	Adélie penguin, *Pygoscelis adeliae;* Chinstrap penguin, *P. antarctica*; Gentoo penguin, *Pygoscelis papua;* Macaroni penguin, *Eudyptes chrysolophus*; Black-browed albatross, *Thalassarche melanophris*; Antarctic petrel, *Thalassoica antarctica*; Cape petrel *Daption capense*; Antarctic fur seal, *Arctocephalus gazella*	LC, i LC, d LC, s VU, d LC, i LC, s LC, s LC, d

NOTES: Catch is for 2017 (CCAMLR, 2018) and biomass estimate is for 2000 (Fielding *et al.*, 2011). Two operators, catching >50% of the total catch are MSC certified. CCAMLR's remit includes minimising impacts on "dependent and related populations" which includes all predators of the fished stock. The listed predators are those monitored by the CCAMLR Ecosystem Monitoring Programme (Agnew, 1997).

Case study

Antarctic krill, *Euphausia superba*, a pelagic crustacean endemic to the Southern Ocean, has a maximum length of ~6 cm, a lifespan of ~7 years, and spawns from age ~2 years (Reiss, 2016). It has a high biomass (~ 215 million tonnes), high yet locally variable production (~100 to 500 Mt yr^{-1}) and a highly aggregated distribution (Atkinson *et al.*, 2008;

2009; Tarling *et al.*, 2009). These qualities contribute to krill being the main prey of many birds, seals, whales and fish (Trathan & Hill, 2016). It is currently fished mainly in shelf and shelf-break areas of the southwest Atlantic sector (Nicol & Foster, 2016). Catches are ~250kt yr^{-1} and the main products are meal for animal feed and omega-3 rich oil for human consumption (Nicol & Foster, 2016). There is concern that concentrated fishing could negatively impact land-based predators by reducing local prey availability, particularly where fishing effort is concentrated close to breeding colonies (Constable *et al.*, 2000; Nicol & Foster, 2016; Trathan & Hill, 2016). The fishery is managed by the international Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to maintain the regional (c. 3.5 million km^2) krill spawning stock biomass within bounds defined by two reference points (Constable *et al.*, 2000; Hill 2013). CCAMLR members include 24 countries plus the European Union.

The CCAMLR Ecosystem Monitoring Programme (CEMP) was established in 1987 to monitor ecological variability in relation to environmental change and fishing. The CEMP monitors a selection of variables for 4 species of penguin, 1 albatross, 2 petrels and 1 seal at breeding colonies throughout the Southern Ocean (Agnew, 1997). Analyses support the expectation that some predator indices are linked to krill availability (Reid *et al., 2*005, Hinke *et al.*, 2007). Data on the krill stock include fishery-dependent data on catch, effort and body length, and annual summer acoustic biomass estimates from local-scale surveys (~10,000 to 125,000 km^2) (Hill *et al.*, 2016), although the most spatially extensive of these survey series (Reiss *et al.*, 2008) stopped in 2011. The CEMP monitoring and the fishery-independent krill surveys are provided by the national Antarctic science programs of various CCAMLR members, usually following standard protocols agreed within CCAMLR.

The CCAMLR has objectives which are stated in its founding Convention[1] and which include maintenance of target stocks and ecological relationships, avoidance of irreversible change and restoration of depleted populations (Constable *et al.*, 2000). It has established reference points for the krill spawning stock at the regional scale, but not at finer spatial scales. These reference points include a provision to reserve krill production for predators by maintaining average krill stock size above 75% of its "unexploited" level (Constable *et al.*, 2000; Hill, 2013).

[1] https://www.ccamlr.org/en/organisation/camlr-convention-text, accessed 12th November 2019.

The current annual krill catch limit is determined from a model which simulates variability in regional biomass over 20 years to identify a fixed harvest rate that conforms with the krill reference points (Constable *et al.*, 2000). This harvest rate is multiplied by an estimate of "unexploited" stock size, based on data collected during a synoptic survey throughout the southwest Atlantic sector in 2000 to give a catch limit of 5.61 million tons. This method could be used to modify catch limits in response to new data on krill stock status including that from a new synoptic scale survey conducted in early 2019. These data have not yet been used to modify catch limits. Also, the effective catch limit is a more conservative arbitrary interim limit of 620k tons which applies pending spatial subdivision of the total catch limit (Hill *et al.*, 2016). The interim catch limit is subdivided amongst four ~1 million km^2 "subareas". CCAMLR intends to increase the spatial resolution of management to minimise impacts on predators before increasing the catch limit. Its preferred approach to achieve this is termed "feedback management" (Nicol & Foster, 2016) although the technical details of this approach, including data requirements, reference points and decision rules are currently unspecified.

There is no agreed procedure for producing annual estimates of the controlled variable (regional krill spawning stock biomass) from regular monitoring data, and no management decisions have been taken in response to changes in these data. The Convention includes the following objective: "the restoration of depleted populations to the levels… which ensure… stable recruitment". The main depleted predator populations at the time that the Convention came into force were baleen whales and Antarctic fur seals. CEMP does not monitor baleen whales or the overall size of the Antarctic fur seal population. Also, the phrase "levels which ensure stable recruitment" has not been translated into an operational reference point. Thus, while the Convention is explicit that, for depleted predator populations, the population level is a variable of interest, the current management procedure for the krill fishery (Constable *et al.* 2000) does not define any predator control variables or reference points, and does not consider predator monitoring data. The rationale for the interim catch limit included the observation that there was no evidence that this level of catch significantly impacts krill predators, but this observation was not accompanied by any analysis of predator data (SC-CAMLR 1991).

CCAMLR is generally considered effective at implementing catch control measures (e.g. Cullis-Suzuki & Pauly, 2010) which is evidenced by the successful closure of a subarea when its interim krill catch limit is reached (Hill *et al.*, 2016).

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Table S6. Scores for the *Antarctic krill and its predators in the Southwest Atlantic sector of the Southern Ocean* case study. A score of 1 indicates the presence of the relevant component of a feedback loop. Further details as Table S2.

	Target species feedback loop (objectives for Antarctic krill and fishery)		**Predator feedback loop (additional objectives for krill predators)**	
Component	Score	Evidence	Score	Evidence
Variable	1	The fishery is managed … to maintain the regional (c. 3.5 million km^2) krill spawning stock biomass	1	the Convention is explicit that, for depleted predator populations, the population level is a variable of interest
Data	1	an estimate of "unexploited" stock size, based on data collected during a synoptic survey throughout the southwest Atlantic sector in 2000	1	CEMP monitors a selection of variables for 4 species of penguin, 1 albatross, 2 petrels and 1 seal at breeding colonies throughout the Southern Ocean
Estimate	0	There is no agreed procedure for producing annual estimates of the controlled variable (regional krill spawning stock biomass) from regular monitoring data.	0	The current management procedure for the krill fishery … does not consider predator monitoring data… The rationale for the interim catch limit ... was not accompanied by any analysis of predator data
Reference point	1	[CCAMLR] has established reference points for the krill spawning stock at the regional scale	0	The current management procedure for the krill fishery … does not define any predator … reference points
Adjustment method	1	The current annual krill catch limit is determined from a model … to identify a fixed harvest rate that conforms with the krill reference points. … This method could be used to modify catch limits in response to new data on krill stock status	0	The current management procedure for the krill fishery … does not consider predator monitoring data
Implementation	1	CCAMLR is generally considered effective at implementing catch control measures		*NA*
Total score	5		2	

Case study 4: Lesser sandeel and black legged kittiwake in the North Sea

Table S7. Summary of *Lesser sandeel and black legged kittiwake in the North Sea* case study. Further details as Table S1.

Location	Scale (km^2)	Fished species	Catch (t), Biomass (t), (C/B)	Management	Predators	Red list
North Sea (Northeast Atlantic)	570,000	Lesser sandeel, *Ammodytes marinus*	518,277 3,102,166 (16.7%)	International (EU) MSC certified operators	Black legged kittiwake, *Rissa tridactyla*	VU, d

NOTES: Catch and biomass estimate are for 2017 (ICES, 2018). The spawning stock estimate for 2017 was 589,296 t. The Danish fleet has been MSC certified since 2017 and the Norwegian fleet since 2018.

Case study

Five species of sandeel (family Ammodytidae) occur in the North Sea, with the most abundant, *Ammodytes marinus* being a key prey of breeding seabirds (Furness and Tasker 2000) and supporting a fishery for fish meal and fish oil production (ICES, 2017). Hereafter, "sandeels" refers to *A. marinus*. Sandeels spawn in December-January. Eggs are laid on the seabed, hatching into the water column in February-April (Wright and Bailey, 1996; Régnier *et al.*, 2017). After metamorphosis around May-June, juveniles settle into suitable patches of sandy sediment alongside adults (Winslade, 1974; Wright and Bailey, 1996). After settling, individuals undertake daily migrations into the water column to feed on zooplankton, especially calanoid copepods (Reay, 1970; Winslade, 1974; van der Kooij *et al.*, 2008; van Deurs *et al.*, 2011). Once critical size and body condition are reached in late summer, sandeels bury into the sediment to overwinter (Bergstad et al, 2002; van Deurs *et al.*, 2011b; Rinsdorf *et al.*, 2016). The fishery is active mostly in spring-early summer in order to target 1+ fish and avoid harvest of 0-group fish (ICES, 2017). Age 1-2 individuals tend to constitute the majority of stock biomass in heavily fished stocks (ICES, 2017). Maturation mostly occurs at age 2, but can occur at age 1 (Boulcott *et al.*, 2007).

Until recently, North Sea sandeels were managed as two distinct management units, one small unit around Shetland, and a much larger management unit through the rest of the

North Sea. However, sandeels are patchily distributed because of their requirement for sediments containing a high proportion of coarse sand with little silt (Wright *et al.*, 2000; Holland *et al.*, 2005; Jensen *et al.*, 2011) and tendency to remain in areas in which they settle (Gauld, 1990; Wright *et al.*, 2019). Consequently, exchange among grounds is limited by the dispersal of larvae and early juvenile phases (Wright, 1996; Proctor *et al.*, 1998; Christensen *et al.*, 2008). Recognising the limited connectivity among regions, differences in growth and independent stock dynamics, the North Sea is now managed as seven separate stocks of sandeels (ICES, 2017; Wright *et al.*, 2019).

Sandeels are affected by environmental changes (Macdonald *et al.*, 2015). Sandeel recruitment is sensitive to changes in plankton phenology as the early growth and survival are linked to the match between hatching and the onset of the spring bloom (Wright and Bailey, 1996; Régnier *et al.*, 2017). Recent warming and changes in plankton distribution and phenology (Beaugrand *et al.*, 2002) could be having a major effect on sandeel growth and survival (van Deurs *et al.*, 2009; 2014) although the importance of changing species composition is uncertain (Eerkes-Medrano *et al.*, 2017). In addition, the fishery can impose high mortality on sandeels, often concentrated for a period of years on particular stocks when high catch per unit effort can be maintained, which can result in reduced stock biomass and a skew towards youngest age classes in the stock (ICES, 2017). Many seabird species in the northern sector of the North Sea, including kittiwakes *Rissa tridactyla*, are dependent on sandeels for food owing to a lack of suitable alternative prey species (Furness and Tasker 2000). As a consequence, kittiwake breeding success and survival are positively correlated with sandeel stock size across this region (Poloczanska *et al.* 2004, Daunt *et al.* 2008, Carroll *et al.* 2017).

The sandeel fishery started in the 1950s, reaching peak landings of around 1 million tonnes in the late 1990s, before declining to 100,000 – 400,000 tonnes per year since 2003 (Furness, 2002; Reilly *et al.*, 2014; ICES, 2017). Although high catches were initially taken from banks off the coast of Denmark, the fishery has tended to concentrate on the Dogger Bank, a shallow area in the southern North Sea. A sandeel fishery started at Shetland in the early 1970s with 0-group being a significant component of catches. Assessments of this stock showed a decrease in recruitment after 1982 that was concomitant with breeding failures of many species of seabirds at Shetland (Furness and Tasker, 2000; Furness, 2007). Despite fishery closures and stricter management, recruitment has generally been poor since 2000, which may be related to climate-change effects on the export of larvae to Shetland from more productive aggregations (Wright, 1996; Proctor *et al.* 1998) and increasing top-down predation (Frederiksen *et al.*, 2007).

When the fishery operated off east Scotland in the 1990s, sandeel abundance declined and kittiwakes *Rissa tridactyla* in the region showed reduced breeding success and survival (Rindorf *et al.*, 2000; Frederiksen *et al.*, 2004; Daunt *et al.*, 2008). Breeding numbers and productivity of kittiwakes and other seabird species are monitored annually at many colonies around the British Isles by volunteers providing data to the Joint Nature Conservation Committee (JNCC), who make this available to the public online. A closed area encompassing much of Scotland's east coast was established in 2000 to protect the sandeel stock. Sandeel biomass initially rebounded, but there have been few large year-classes since, likely due to worsening environmental conditions (Greenstreet *et al.*, 2010; Régnier *et al.*, 2017). The closure, which is still in place, appeared to provide some benefit to kittiwakes (Frederiksen *et al.*, 2004; Daunt *et al.*, 2008). The Dogger Bank an important sandeel stock that has been the main target of the sandeel fishery in recent years (Christensen *et al.*, 2008; ICES, 2017). The western edge of the Dogger Bank and the smaller sandbanks to the south and west are some of the most important fishing grounds (ICES, 2007; Engelhard *et al.*, 2008; South *et al.*, 2009; Jensen *et al.*, 2011), but are also important feeding areas for breeding kittiwakes from the largest kittiwake colony in the North Sea, at Flamborough and Filey Coast (Carroll *et al.*, 2017). The colony itself is within a designated Special Protection area which encompasses cliff and intertidal habitats. There is evidence that high fishing mortality imposed on the Dogger Bank stock resulted in reduced breeding success of kittiwakes there (Carroll *et al.*, 2017).

The three smallest North Sea sandeel stocks (Areas 5, 6 and 7, respectively, west Norway, Kattegat and Shetland) do not now support fisheries, and so there are not adequate data for analytical assessments of those stocks (ICES, 2017). For four stocks (area 1 – Dogger Bank, area 2 Danish coast, area 3 south Norway, area 4 east Scotland), analytical stock assessments, based on catch and effort data supplemented with dredge data from a fishery independent survey, are carried out annually. These estimate stock biomass and the appropriate quota that can be set based on an escapement strategy (ensuring that adequate numbers of fish remain after harvest to avoid reduced reproductive capacity by examining the historical stock-recruitment relationship and defining the limit of spawning stock biomass that is considered likely to produce good recruitment). The stock assessment models incorporate age-specific estimates of natural mortality derived from estimates of the biomass of the major fish predators of sandeels and the composition of their diets. The models aim to ensure that there is less than a 0.05 risk of spawning stock biomass falling below the defined reference point threshold of minimum acceptable spawning stock biomass. The models used incorporate some elements of variance, but treat other parameters as fixed values rather than estimates with confidence limits (e.g. natural mortality estimates) and so probably underestimate variance in the assessment. This may lead to larger catch quotas than are appropriate and may in part explain why spawning stock biomass in recent years has been below reference limits more frequently than the model predicts (ICES, 2017). There has been some misreporting of catches, but this has apparently been limited and catches have generally respected the set quotas.

Although there is strong evidence that reducing sandeel stock biomass below one-third of the long term maximum results in seabird breeding failures (Cury *et al.*, 2011), no thresholds are set for sandeel stock management on the basis of the needs of dependent predators. However, low breeding success of kittiwakes off east Scotland, indicating the poor state of the sandeel stock in that region, led to the closure of a specific sandeel fishing area in 2000. The closure affected a box delimiting an area of a reproductively isolated sandeel aggregation (Wright *et al.*, 1998) which is important for breeding kittiwakes (and other seabirds) along the east coast of Scotland. Breeding success of kittiwakes was proposed by ICES (1999) as a criterion for deciding on re-opening the closed area, but the European Commission did not accept the proposal following complaints by the fishing industry. The UK government has defined an indicator (reference point) of good environmental status based on black legged kittiwakes, but this reference point is not used to set quotas for the sandeel fishery.

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Table S8. Scores for the *Lesser sandeel and black legged kittiwake in the North Sea* case study. A score of 1 indicates the presence of the relevant component of a feedback loop. Further details as Table S2.

	Target species feedback loop (objectives for Lesser sandeel and fishery)		**Predator feedback loop (additional objectives for black legged kittiwake)**	
Component	Score	Evidence	Score	Evidence
Variable	1	…spawning stock biomass falling below the defined reference point threshold of minimum acceptable spawning stock biomass	0	Breeding success of kittiwakes was proposed by ICES (1999) as a criterion for deciding on re-opening the closed area, but the European Commission did not accept the proposal following complaints by the fishing industry.
Data	1	analytical stock assessments, based on catch and effort data supplemented with dredge data from a fishery independent survey, are carried out annually	1	Breeding numbers and productivity of kittiwakes and other of seabird species are monitored annually at many colonies around the British Isles by volunteers providing data to the Joint Nature Conservation Committee (JNCC), who make this available to the public online.
Estimate	1	analytical stock assessments … are carried out annually. These estimate stock biomass …	1	low breeding success of kittiwakes off east Scotland, indicating the poor state of the sandeel stock in that region, led to the closure of a specific sandeel fishing area in 2000.
Reference point	1	the defined reference point threshold of minimum acceptable spawning stock biomass	0	no thresholds are set for sandeel stock management on the basis of the needs of dependent predators
Adjustment method	1	analytical stock assessments … are carried out annually. These estimate stock biomass and the appropriate quota that can be set based on an escapement strategy	0	Breeding success of kittiwakes was proposed by ICES (1999) as a criterion for deciding on re-opening the closed area, but the European Commission did not accept the proposal following complaints by the fishing industry.
Implementation	1	There has been some misreporting of catches, but this has apparently been limited and catches have generally respected the set quotas.		*NA*
Total score	6		2	

Case study 5: Groundfish and Steller sea lion (western stock) in the U.S. North Pacific Ocean

Table S9. Summary of *Groundfish and Steller sea lion in the U.S. North Pacific Ocean* case study. Further details as Table S1.

Location	Scale (km^2)	Fished species	Catch (t), Biomass (t), (C/B)	Management	Predators	Red list
US Northeast Pacific	1,500,000	Walleye pollock, *Gadus chalcogrammus*; Pacific cod, *G. macrocephalus*; Atka mackerel, *Pleurogrammus monopterygius*	1,881,000 17,500,000 (11.3%)	National (US) MSC certified fisheries.	Steller sea lion *Eumetopias jubatus* (western stock)	EN, i

NOTES: Catch and biomass estimates are for 2017 for all three species in the eastern Bering Sea, Gulf of Alaska, and Aleutian Islands combined (NPFMC 2017, 2018a, 2018b). Fisheries for *G. chalcogrammus* and *G. macrocephalus* are MSC certified. Global population of *E. jubatus*: NT, increasing.

Case study

Groundfish fisheries in the U.S. North Pacific Ocean are managed according to individual stocks or stock complexes (comprising several species) by the North Pacific Fishery Management Council (Council) and the National Marine Fisheries Service under authority of the Magnuson-Stevens Fishery Conservation and Management Act (FCMA; see NPFMC 2017, 2018a, 2018b). Species vulnerable to these fisheries are categorized as being **Target** (47 “stocks” within the Bering Sea/Aleutian Islands (BSAI) and Gulf of Alaska (GOA) ecosystems), **Prohibited** (6 incidentally caught species groups), or **Forage** (8 families of fish as well as euphausiids that are considered to be prey for other marine species, hence directed fisheries are prohibited). Target species catches are dominated by three species that are also primary prey for marine mammals and birds: walleye pollock (*Gadus chalcogrammus*), Pacific cod (*G. macrocephalus*), and Atka mackerel (*Pleurogrammus monopterygius*), and these are the focus of this discussion.

Fisheries for the focal species occur on the shelf (generally less than 200m) and along the shelf-break, areas that are also important foraging habitats for Steller sea lions (*Eumetopias jubatus*; SSL). The western stock of SSL is listed as 'endangered' under the U.S. Endangered Species Act (ESA). Abundance of western SSL in Alaska declined >80% between the 1970s and early 2000s (NMFS 2008), but has shown a gradual increase through 2016 (Fritz *et al.* 2016; Sweeney *et al.* 2016). However, some regions (e.g., the Aleutian Islands) continue to decline. Relationships between range-wide or local target-species abundances (or catches) and Steller sea lion population performance are poorly understood which makes linking management measures with expected responses challenging. Early abundance declines in the 1970s and 1980s were likely due to a combination of factors, both direct (incidental take in fisheries and illegal shooting) and indirect (changes in prey availability due to environmental changes and/or fisheries; Atkinson *et al.* 2008). Sources of direct mortality were largely eliminated in the 1990s following ESA-listing and recent fishery management actions have focussed on minimizing indirect impacts, namely to local prey availability (NMFS 2008).

The U.S. National Marine Fisheries Service (NMFS) monitors abundance trends of groundfish and Steller sea lions through regular, in most cases annual, surveys. Additionally, most groundfish stocks have detailed age-structured assessments which support acceptable biological catch (ABC) recommendations based on single-species reference points (NMFS 2016a, b). These values lead to total allowable catch (TAC, where TAC ≤ ABC) specifications by the Council after considering socio-economic and environmental factors. Within each ecosystem, TACs are constrained such that their sum does not exceed the optimum yield of 2 million t in the BSAI and 0.8 million t in the GOA. The objectives specified in the FCMA are to prevent overfishing, rebuild overfished stocks, increase long-term economic and social benefits, and ensure a safe and sustainable supply of seafood, which includes maintenance of target stock abundances above minimum thresholds at the ecosystem scale. The management system, thanks to an extensive scientific observer program, ensures that catches remain at or below TACs.

The terrestrial breeding range of the SSL extends across the North Pacific Ocean from eastern Russia to the central California (U.S.) coast. Two separate stocks, the ESA-threatened eastern and the ESA-endangered western, were recognized in 1997 and are divided at 144W. By 2013, the eastern stock had recovered following 30+ years of population growth and was removed from ESA protection. Management of western SSL is guided by an ESA Recovery Plan (NMFS 2008), which lays out requirements for de-listing (i.e., recovery), including both regional and range-wide (U.S. and Russia) population trends. De-listing requires 3% average annual population (juveniles and adults) growth over 30 years in the U.S. region, with stable or increasing trends in 5 of 7 sub-regions (including the Russian region) and no sub-regional declines of >50% over the same period (NMFS 2008). Interim reclassification to ESA-threatened status requires statistically significant population growth over 15 years and consistent trends in 5 of 7 sub-regions (NMFS 2008).

Recovery objectives for SSL are considered in fishery management through the ESA Section 7 process, whereby the 'action' agency (NMFS Sustainable Fisheries) consults with the 'consulting' agency (NMFS Protected Resources) to ensure that the groundfish fishery avoids jeopardizing the recovery or adversely modifying critical habitat of SSL (and other listed species). As a result of multiple consultations since 1990, fisheries-management actions have been taken in the U.S. to help recover SSL, such as fishing restrictions (including closures) near terrestrial SSL haulout and rookery sites and suspension of fishing on any of the three target prey species should their biomass fall below 20% of their estimated unfished levels. However, SSL population performance is not specifically tied to any U.S. or Russian fishery-management measure (NMFS 2014). Accounting for the cumulative effects of fishing dating to the early 1960s (e.g., hypothesizing that fishing has reduced carrying capacity) has been limited. Ecosystem objectives listed in other U.S. laws (e.g., Marine Mammal Protection Act) include maintenance of healthy and stable marine ecosystems and optimum populations of marine mammals, maintenance of ecological relationships, and avoidance of irreversible change, but due to separate regulatory systems these objectives are not directly considered in the annual TAC setting or fishery management processes.

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Table S10. Scores for the *Groundfish and Steller sea lion (western stock) in the U.S. North Pacific Ocean* case study. A score of 1 indicates the presence of the relevant component of a feedback loop. Further details as Table S2.

	Target species feedback loop (objectives for groundfish stocks and fishery)		**Predator feedback loop (additional objectives for Steller sea lion (western stock))**	
Component	Score	Evidence	Score	Evidence
Variable	1	maintenance of target stock abundances above minimum thresholds	1	requirements for de-listing (i.e., recovery), include both regional and range-wide population trends
Data	1	(NMFS) monitors abundance trends of groundfish and Steller sea lions through regular, in most cases annual, surveys. Additionally, most groundfish stocks have detailed age-structured assessments	1	(NMFS) monitors abundance trends of Steller sea lions through regular, in most cases annual, surveys.
Estimate	1	Most groundfish stocks have detailed age-structured assessments	1	(NMFS) monitors abundance trends of Steller sea lions through regular, in most cases annual, surveys… Management of western SSL is guided by an ESA Recovery Plan
Reference point	1	acceptable biological catch (ABC) recommendations based on single-species reference points	0	Ecosystem objectives [are] listed in other U.S. laws [but] are not directly considered in the annual TAC setting or fishery management processes
Adjustment method	1	detailed age-structured assessments support acceptable biological catch (ABC) recommendations… [which] lead to total allowable catch (TAC, where TAC ≤ ABC)	0	SSL population performance is not specifically tied to any fishery management measure
Implementation	1	The management system, thanks to an extensive scientific observer program, ensures that catches remain at or below TACs.		*NA*
Total score	6		3	

Case study 6: Peruvian anchovy and seabirds in the Humboldt Current system

Table S11. Summary of *Peruvian anchovy and seabirds in the Humboldt Current system* case study. Further details as Table S1.

Location	Scale (km^2)	Fished species	Catch (t), Biomass (t), (C/B)	Management	Predators	Red list
North-central Humboldt (Southeast Pacific)	550,000	Peruvian anchovy, *Engraulis ringens*	2,983,944 7,780,000 (38%)	National (Peru) Not MSC certified	Peruvian booby, *Sula variegata*; Guanay cormorant, *Leucocarbo bougainvillorum*; Peruvian pelican, *Pelecanus thagus*; South American fur seal, *Arctocephalus australis*; South American sea lion, *Otaria flavescens*	LC, s NT, d NT, i VU, u LC, s

NOTES: The biomass estimate is for March/April 2017 (IMARPE 2017). Global population of *A. australis*: LC, increasing.

Case study

Peruvian anchovy, *Engraulis ringens*, is a small pelagic fish endemic to the Humboldt Current System, managed as two stocks by the Peruvian authorities. The North-Central stock (from the Ecuador-Peru border to 16° South), is most important in terms of fish abundance and economic activity, and the Southern stock (from 16 to 27° South, latitude of Antofagasta, Chile) is shared with Chile. This species may attain ~20cm length, becomes mature and recruits to the fishery at 1 year old (~12 cm length), and has a life expectancy of around 3 years. This species produces large biomasses, about 2-18 million tonnes for the North-Central stock and 3-6 million tonnes for the Southern stock (Oliveros-Ramos *et al.* 2010, Oliveros-Ramos in press, Chavez *et al.* 2008, Donlan *et al.* 2014). Biomass is highly variable at seasonal, interannual (El Niño and La Niña events), decadal and centennial scales (Chavez *et al.* 2008; Gutierrez *et al.* 2011). This forage fish sustains large populations of guano-producing seabirds (~3.3 million in 2014 with ~1.6 million Peruvian booby, *Sula variegata*, ~1.7 million Guanay cormorants, *Leucocarbo bougainvillii*, and ~50,000 Peruvian pelicans, *Pelecanus thagus*; AGRO RURAL, unpublished data; Passuni *et al.* 2016) and pinnipeds (~ 10,000 South American fur seals, *Arctocephalus australis* and ~130,000 South American sea lions, *Otaria flavescens*; IMARPE, 2015, unpublished data). Peruvian anchovy is highly gregarious and distributes in space in constantly moving aggregations (schools and clusters of schools, Bertrand *et al.*, 2008, Peraltilla and Bertrand, 2014). Moreover, a particularly intense and shallow oxygen minimum zone constrains its vertical distribution (Bertrand *et al.* 2010) and impacts its availability to predators (Boyd *et al.* 2015, 2016; Barbraud *et al.* 2018).

A large-scale, industrial purse-seine fishery has exploited Peruvian anchovy since the 1950s, mainly for production of fishmeal and fish oil. This fishery went through a famous collapse in the early 1970s (related to overfishing, El Niño events and decadal climatic conditions) and a subsequent recovery. Annual landings over the past 20 years have ranged between 2 and 10 million tonnes (2 to 4 million tonnes in the most recent years for the North-Central stock) and Peru provides half and a third of current world production of fishmeal and oil respectively (Fréon *et al.* 2014). The Peruvian fishery is managed by the ministry of production (PRODUCE), based on scientific advice from the Peruvian Institute of the Sea (IMARPE). This advice includes two main objectives for the North-Central stock which are defined in terms of reference points: 1) to maintain a spawning stock biomass of at least 5 million tonnes at the beginning of each reproductive season; and 2) a target exploitation rate of 0.35. The regulatory system is based on fishing effort, catch restrictions and spatial closures. Two fishing seasons have been established to account for the two annual reproductive periods of anchovy, there is a minimum purse seine mesh size (13mm), a total allowable catch (TAC) for each stock, an allocation of the TAC into individual shares (since 2009), a minimum catch size (12cm) and temporal spatial closures for areas with catch exceeding a 10% of juveniles (PRODUCE, 2016).

To deal with the particularly intense natural variability, IMARPE performs extraordinarily intensive and continuous ecosystem monitoring. Two to four scientific surveys are conducted each year, most of them covering the entire coast of Peru. These surveys include hydroacoustic biomass evaluation, egg and larvae assessment, plus length structure and gonadosomatic monitoring. The species and size composition of landings are monitored daily. Observers aboard vessels fully monitor about 2% of the fishing trips and VMS is mandatory for the entire fleet. There are annual censuses of pinniped populations and AGRO RURAL (the public institution in charge of guano harvesting) performs monthly censuses of the three guano producing seabird species (listed above). The ability of those species to buffer food shortages to some extent makes it difficult to disentangle the relative effects of intense climate variability and the heavy fishing pressure on the trajectory of their populations. However, some recent studies provide evidence of possible competition between seabirds and the fishery for access to anchovy (Bertrand *et al.* 2012, Barbraud *et al.* 2018).

IMARPE uses an assessment model for anchovy that integrates size-structured abundance and stock biomass from scientific surveys and fishery landings to forecast anchovy biomass with a time horizon of a few months (Oliveros-Ramos *et al.* in press, IMARPE 2015a, 2015b, 2016). Data uncertainty is taken into account using bootstrapping procedures and an evolutionary algorithm is used for calibrating the assessment model. The model is used to forecast size-structured abundance over several months (until the next anchovy reproductive season). The model takes into account environmental variability (tuning natural mortality and growth parameters according to three qualitative environmental scenarios) and variable exploitation scenarios (time allocation and size structure of the catches). The protocol for estimating maximum allowable catch given reference points and the state of the spawning stock biomass in the current year is described in IMARPE (2015a, 2015b, 2016). Regulations are highly effective. The length of the fishing season is determined according to landings monitored on a daily basis. Once the seasonal quota is met, the fishery is immediately closed. Peru has a clear aspiration to implement an ecosystem approach to fishery management. In that sense, a network of national reserves (33) was implemented in 2009 (RNSIIPG - , decreto supremo n. 024-2009-MINAM), to reduce disturbance at the islands and headlands used as breeding sites by seabirds and marine mammals for their breeding. These reserves include a small (c. 10 km)) buffer in surrounding waters. However, no explicit state variables or biological reference points for top predators or other related populations are included in the current anchovy fishery management protocol. Nor does the protocol make use of predator population estimates.

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Table S12. Scores for the *Peruvian anchovy and seabirds in the Humboldt Current system case* study. A score of 1 indicates the presence of the relevant component of a feedback loop. Further details as Table S2.

	Target species feedback loop (objectives for Peruvian anchovy and fishery)		**Predator feedback loop (additional objectives for seabirds)**	
Component	Score	Evidence	Score	Evidence
Variable	1	…to maintain a spawning stock biomass of at least 5 million tonnes at the beginning of each reproductive season.	0	no explicit state variables … for top predators … are included in the current anchovy fishery management protocol.
Data	1	2 to 4 scientific surveys each year…The species and size composition of landings are monitored daily and observers at sea monitor fully about 2% of the fishing trips	1	census of pinnipeds populations are performed each year. In addition, AGRO RURAL, the public institution in charge of guano harvesting, is performing monthly census of the three guano producing seabird species
Estimate	1	IMARPE uses an anchovy assessment model that integrates size structured abundance and stock biomass from scientific surveys and fishery landings to forecast anchovy biomass with a time horizon of a few months	0	Nor does the protocol make use of predator population estimates.
Reference point	1	a spawning stock biomass of at least 5 million tonnes at the beginning of each reproductive season.	0	no explicit …. biological reference points for top predators … are included in the current anchovy fishery management protocol.
Adjustment method	1	The protocol for estimating maximum allowable catch given reference points and the state of the spawning stock biomass in the current year is described in IMARPE (2015a, 2015b, 2016).	0	no explicit state variables or biological reference points for top predators … are included in the current anchovy fishery management protocol.
Implementation	1	Regulations are highly effective. The length of the fishing season is determined according to landings monitored on a daily basis. Once the seasonal quota fulfilled, the fishery is immediately closed.		*NA*
Total score	6		1	