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HUNGRY OCEANS:
WHAT HAPPENS WHEN THE PREY IS GONE?

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TABLE OF CONTENTS

HUNGRY OCEANS

Overview

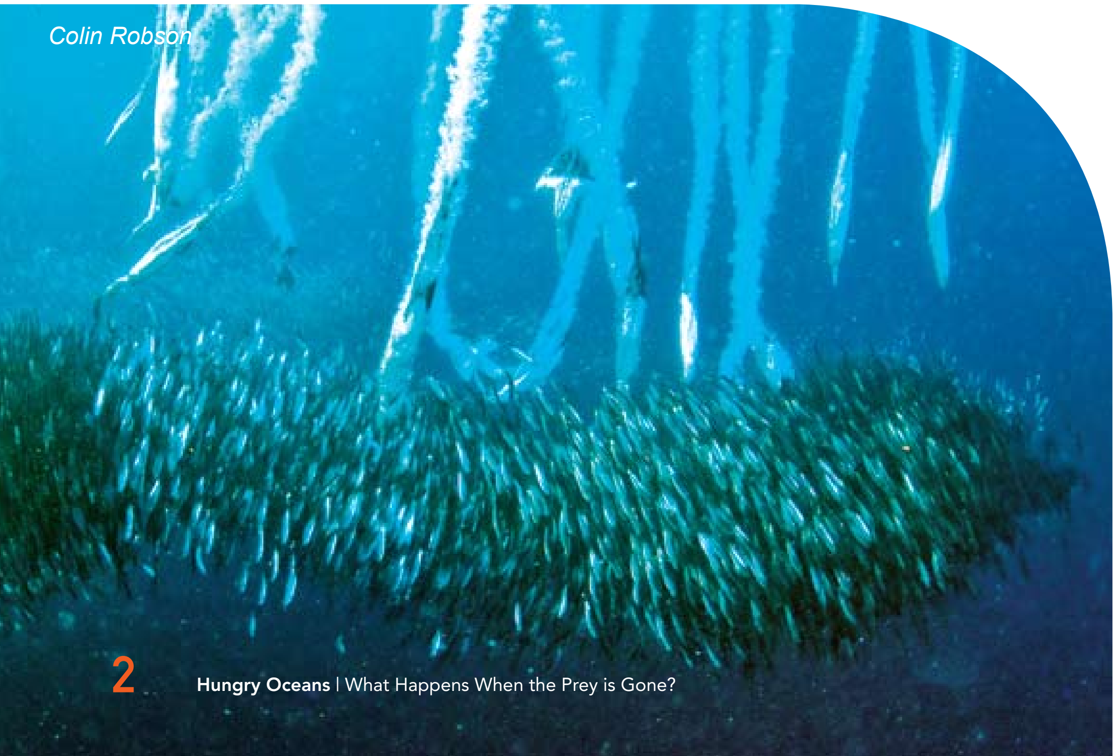
According to conventional wisdom, small, fast-growing fish are impossible to overfish because their populations are so large and grow so quickly. Yet we are now seeing disquieting signs that conventional wisdom is wrong. Most significantly, scientists are reporting ocean predators emaciated from lack of food, vulnerable to disease and without enough energy to reproduce. Scrawny predators—dolphins, striped bass, and even whales—have turned up along coastlines around the world. Recreational fishermen are losing both their target fish—and their bait. Fishing communities are losing their livelihoods.

Because we have overlooked hungry predators, we have allowed overfishing of their prey, causing food shortages in the ocean. In addition, by fishing where and when they are breeding, we are driving prey populations to the brink of disaster, and in some cases beyond it.

At the same time, our continued demand for salmon, tuna, and other large predators has driven explosive growth in aquaculture. Rather than relieving pressure on wild fish, growing these large carnivores requires a steady supply of prey that are caught and ground into oil and meal. As the industry grows, it is straining the existing supply of prey fish, putting additional pressure on populations that cannot supply the demand.

Because populations of many small prey species are sensitive to changes in temperature, ocean currents, and El Niño, they are particularly vulnerable to climate change. For predators, even small climate-driven shifts in the local availability of squid and other prey during breeding can lead to malnourished young or abandonment.

For many prey species, humans have replaced their natural predators—the other fish, the sea birds, the marine mammals—all the species that depend on them for their existence. Fishermen who catch prey species are beginning to turn up empty nets. Unless the current trends are reversed, we can look forward to a future with increasingly hungry oceans.



Colin Robson

Prey species underpin marine food webs around the world

Seabirds dive on a herring school

PREDATORS NEED THEIR PREY

The great predators of the ocean spend most of each day hunting for food. Scientists studying sperm whales estimate they spend nearly three quarters of their time searching for squid and other prey (Watwood et al. 2006). Abundant schooling fish fuel the blue marlin's speed and strength (Abitia Cardenas 1999), and are staples in the diet of many whales.

Hungry animals may fail to nurse or find enough food for their young, and sometimes skip breeding season entirely. During an eight-year prey shortage in the Faroe Islands, no Arctic tern chicks survived (Wright et al. 1996). During another food shortage, Galápagos penguins were forced to "desert their eggs and chicks to search for food to save themselves while their chicks starved to death." (Boersma et al. 2008) When long-lived animals like whales go hungry, the next generation is at risk.

Predators are normally forced to rely on less desirable, less nutritious, or less abundant prey for short periods of time. If this happens too often or for long periods of time, however, predators can become malnourished and vulnerable to disease. Poor health and food shortages may have left striped dolphins vulnerable to a 1990s plague in the Mediterranean that led to many deaths (Aguilar and Raga in Bearzi et al. 2003).

ECOSYSTEM RESILIENCE AT RISK

Only now that predators are going hungry are forage fish becoming recognized for their role at the foundation of marine food webs. Predators consume great quantities of tiny fish—often all the same species. Within an ecosystem perhaps only two or three species fill that role (Cury et al. 2000). If one prey population crashes, few options are left for its predators. This low level of redundancy can result in a lack of resilience to other stresses on the ecosystem.

Shannon Johnson

PREDATORS:

Bluefin Tuna and Other Big Fish

Loss of prey for large predatory fish translates to loss of prey for commercial fishermen and recreational anglers, as tuna, salmon, and striped bass go hungry. Species in recovery such as North Atlantic Bluefin Tuna or Striped Bass are particularly in need of abundant prey to rebuild their populations from overfishing.

Northern Atlantic Bluefin Tuna

Bluefin tuna (*Thunnus thynnus*) are some of the largest and fastest fish in the oceans—and also the most valuable, with a record of $173,600 for a single fish (Associated Press 2001). This demand has driven worldwide overfishing of this species, and in the western Atlantic populations have been reduced by more than 80 percent since 1975 (ICCAT 2006). Surprisingly, the basic biology of this fish is just beginning to be understood, including its food-centric migration.

Though bluefin tuna are top predators and opportunistic feeders, their diet is often dominated by one or two favorite prey species that provide optimal sources of energy (Chase 2002). Mass movements of bluefin are synchronized with spawning and feeding schools of various species of prey fish off the east coast of North America. At each step along the way, changing prey populations substantially affect regional aggregations of bluefin tuna, as illustrated in Figure 1.

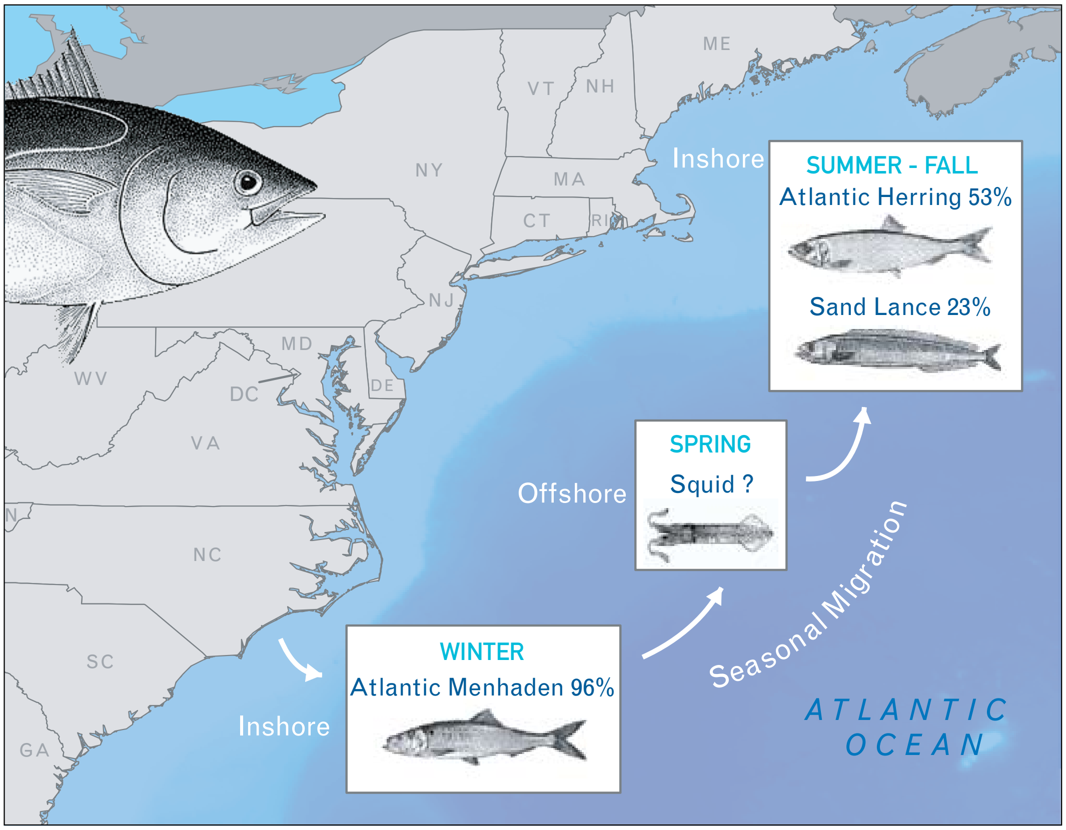


Figure 1. Seasonal prey of Atlantic Bluefin Tuna off the Northeast US
Source: Data in percent of bluefin tuna diet by weight from Chase 2002

Bluefin tuna in the Mediterranean

Oceana / Keith Ellenbogen

During winter months Atlantic bluefin tuna concentrate off the coast of North Carolina where they feast on Atlantic menhaden (*Brevoortia tyrannus*), the staple of their diet. In a recent study of stomach contents from commercially caught tuna, Atlantic menhaden were found 85 percent of the time and made up 95 percent of the bluefin prey by weight (Butler 2007). While predators such as bluefish, striped bass, and weakfish (as well as the commercial fishery) consume much greater quantities of menhaden than tuna, menhaden are essential to bluefin on their winter foraging grounds.

Bluefin tuna concentrate along the southeastern coast of the US during fall and winter, moving north through spring and summer to rich feeding grounds of the North Atlantic (Block et al. 2005). At each location their diet is dominated by one or two preferred fish or squid (Chase 2002). When Atlantic menhaden disperse from concentrated aggregations in North Carolina towards the end of March, bluefin tuna move offshore. Here their diet is poorly known, but they may shift to a wider variety of fish and squid (Dragovich 1970, Boustany, pers. comm.). In June and July bluefin tuna return inshore to New England feeding grounds and a diet dominated by one or two major prey species (Chase 2002).

Mediterranean bluefin tuna feed on squid and small fish, depending on where they live. For juvenile tuna, small schooling fish are particularly important (Sarà and Sarà 2007, Sinopoli et al. 2004).

Pacific Salmon

Like the bluefin tuna, wild Pacific salmon (*Chinook Oncorhynchus tshawytscha, Coho Oncorhynchus kisutch*) prey on krill and small fish throughout their migrations. As they leave their home rivers for the open sea, young chinook and coho salmon (*Oncorhynchus spp.*) feed heavily on Pacific herring, Pacific sand lance, and surf smelt. These prey species spawn in the intertidal zone of many beaches along the Pacific Northwest coast and serve as the first meal for juvenile salmon as they reach the sea, making possible their journey and survival into adulthood. Full-grown salmon range along the west coast of the United States, shifting between springtime krill, crabs and squid to a summertime diet of anchovy, smelt, and sand lance. (FishBase, Hunt 1999, Tyler et al. 2001, Zavolokin et al. 2007, Sakai et al. 2005, Sagawa et al 2007)

Chinook or King Salmon change their diet seasonally

Save Our Wild Salmon

Striped Bass

Striped bass (*Morone saxatilis*) also track the movements of their most important prey, migrating along the coast with Atlantic menhaden and moving between salt and fresh water with river herring. Each spring when striped bass are concentrated in the Chesapeake and Delaware Bay, their diet is dominated by Atlantic menhaden and river herring, and their diets shift to sand lance (also known as sand eel) and other prey as they migrate north each summer (Walter et al. 2003). In fall and winter, striped bass return to focus on menhaden in the bays of Maryland, Delaware, and North Carolina.

Striped bass may struggle with the steady decline of their major prey item, Atlantic menhaden (Uphoff 2003, D.Russell and J.Price, pers. comm.). Menhaden, herring, and bay anchovy are all important prey (Griffin and Magraff 2003, Manooch 1973).

TABLE 1. Recreational and Commercial Fishery Species Dependent on Prey

TARGET SPECIES	STATUS (FAO AND OTHER SOURCES)	SELECT PREY SPECIES
Pacific Salmon	Fully exploited to overexploited	Krill, Squid, Sand Lance, Herring, Sardine, Northern Anchovy, Juvenile Rockfish, Juvenile Atka Mackerel, Walleye Pollock, Lanternfish
Bluefin Tuna	Depleted to severely overexploited	Menhaden, Sand Lance, Herring, Mackerel, Squid
Striped Bass	Recovered	Menhaden, Bay Anchovy, Herring
Pacific Halibut	Fully exploited	Sand Lance, Herring, Walleye Pollock, Squid
South Pacific Hake	Fully exploited to depleted	Anchovy, Anchoveta, Squid, Sardine, Krill
European Hake	Overexploited	Blue Whiting, European Anchovy, European Pilchard, Lanternfish, Horse Mackerel
Southern Hake	Fully exploited to overexploited	Squid, Krill, Blue Whiting

Sources: Butler 2007, Boustany pers. comm., Cartes et al. 2004, Chase 2002, Dragovich 1970, Fishbase, Hunt 1999, IPHC 1998, FAO 2005, Mahe et al. 2007, Paya 1992, Sagawa et al. 2007, Sakai et al. 2005, Tam et al. 2006, Tyler et al. 2001, Velasco 1998, Walter et al. 2003, Zavolokin et al. 2007

John Rix / Fathom This Underwater Productions

Save Our Wild Salmon

Beccy Breach

"One cannot think well, love well, sleep well, if one has not dined well."
— Virginia Woolf

A humpback whale calf swims ahead of its mother

Bryant Austin

PREDATORS:
Whales, Penguins and Other Animals

Ocean predators also include whales, dolphins, seals, sea lions, and birds. Although many of these animals are protected under national and international law, they remain vulnerable to food shortages. They depend on nearby access to squid, krill, and small fish to provide energy reserves for daily survival and for their young.

Endangered species are especially sensitive to food shortages and need abundant food to rebuild their populations. Starving whales are unable to nurse their young, and hungry seabirds may become susceptible to disease. Most animals feed heavily to gain weight before giving birth or after migration, and abundant prey is critical at these times.

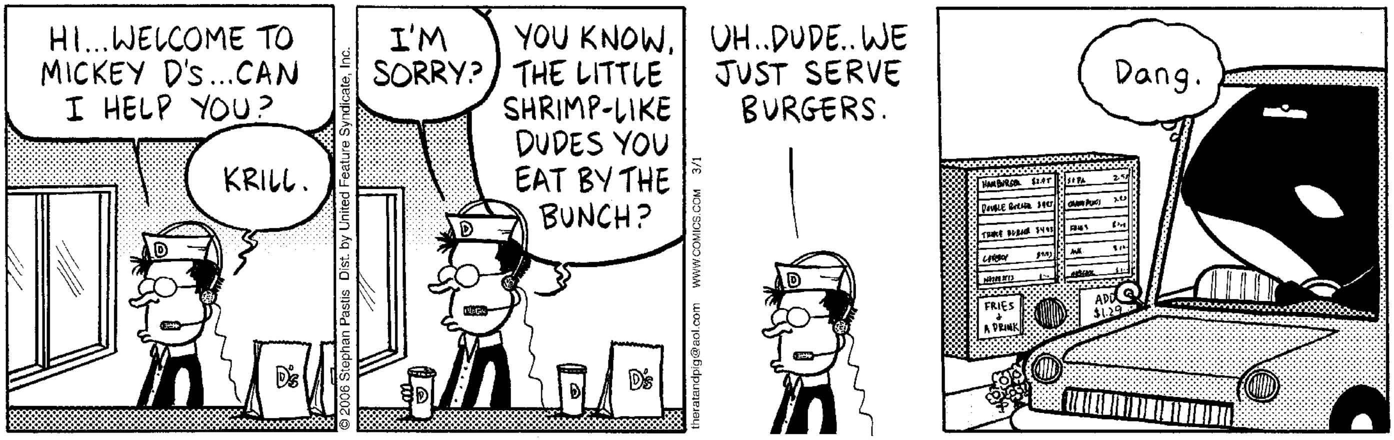
Blue Whales in Southern Chile

The largest animals that have ever lived on earth are powered entirely by krill, and blue whales (*Balaenoptera musculus*) eat a lot to maintain their considerable bulk at 100 feet (30 m) and 200 tons (180 mt) (Clapham et al. 1999, Hucke-Gaete et al. 2006). Blue whales were hunted to the brink of extinction in the 20th century, reduced in the Southern Hemisphere to less than 3 percent of their original numbers (Hucke-Gaete 2003). Now blue whales need more food than ever, to fuel reproduction so their populations can recover.

Krill hotspots such as the Chiloé-Corcovado region in Southern Chile have historically been recognized as blue whale feeding sites. In 1907 a Norwegian whaling ship caught 37 whales in the area and in recent years blue whales have been sighted with increasing frequency; groups of more than 60 whales and cow-calf pairs have been observed (Hucke-Gaete et al. 2006, Hucke-Gaete 2003). The main reason why Southern Hemisphere blue whale populations nurse their calves in Chiloé-Corcovado is to take advantage of the abundant krill supply. This tiny crustacean fuels one of the most important feeding and nursing grounds for Southern Hemisphere blue whales, and is responsible for their gradual recovery from whaling.


Antarctic krill form large swarms

Uwe Kils



Dolphins in the Mediterranean

Mediterranean bottlenose dolphins (*Tursiops truncatus*) have declined significantly, in part because of overfishing of sardines and anchovy that also led to collapse of the fishery in 1987 (Politi 2000). Scientists working in the eastern Ionian Sea found 40 percent of bottlenose dolphins visibly emaciated due to starvation and other causes (Politi et al. 2000).

Short-beaked common dolphins (*Delphinus delphis*) were formerly abundant throughout the Mediterranean, but are now concentrated in a much narrower range near Algeria, Tunisia, Malta, and in the Alboràn, Aegean, Tyrrhenian, and eastern Ionian Seas. Several factors likely contributed to their decline, including reduced access to prey due to overfishing (Bearzi et al. 2003). Poor nutrition may also increase dolphins' susceptibility to disease, an important factor in two mass mortality events in the Mediterranean (Bearzi et al. 2003).

Jesús Renedo / Oceana

A dolphin leaps from the Mediterranean

Marbled Murrelet

Deforestation, nest predation, and oil spills have previously been blamed for driving the marbled murrelet (*Brachyramphus marmoratus*) of central California to the endangered species list. While these factors clearly contributed, recent evidence suggests that the overfishing of sardines and other prey species is are also partly to blame. The diet of the marbled murrelet in the Monterey Bay ecosystem has drastically been altered over the past century (Becker and Beissinger 2006). Fisheries declines, especially the infamous 1950s collapse of the California sardine fishery, have reduced the availability of fish as food for the marbled murrelet. To make matters worse, a marbled murrelet must spend added time and energy catching 80 krill to match the energy found in a single Pacific sardine (Becker and Beissinger 2006).

Magellanic Penguin

Penguins, cormorants, terns and other bird species are currently threatened by a developing anchovy fishery in the Patagonian ecosystem (Skegwar et al. 2007). The Southwest Atlantic anchovy (*Engraulis anchoita*) compose more than half of the Magellanic penguin diet (Skegwar 2007). Despite the central importance of anchovy to the Patagonian food web and the natural variation in its availability, some have pushed to expand the anchovy fishery. If the needs of the ecosystem as a whole are ignored, this fishery could drastically change the food web, with dire consequences for the seabirds of Patagonia.

TABLE 2. Endangered and Protected Species Dependent on Prey Species

ENDANGERED OR PROTECTED SPECIES	STATUS (IUCN)	SELECT PREY SPECIES
Sperm whale	Vulnerable	Squid
Blue whale	Endangered	Krill
Dolphins in the Mediterranean	Data deficient for some species	Anchovy, Sardine, Hake, Whiting, Cephalopods
Harbor porpoise	Vulnerable	Whiting, Herring, Sand Lance, Capelin, Cephalopods
Steller sea lion	Endangered	Sand Lance, Pollock, Herring, Capelin, Squid
Magellanic penguin	Near threatened	Anchovy, Cuttlefish, Hake, Squid, Krill
Marbled murrelet	Endangered	Sardine, Anchovy, Squid, Sand Lance, Herring, Krill, Capelin
Kittiwake	Red-legged: Vulnerable Black-legged: Least concern	Pollock, Herring, Sand Lance, Capelin
Puffin	Least concern	Capelin, Herring, Sand Lance, Squid, Lanternfish

Sources: Baillie and Jones 2003, Barrett and Furness 1990, Bearzi et al. 2003, Blanco et al. 2001, Börjesson 2002, Burkett 1995, COSEWIC 2003, Durant 2003, Falk 1992, Forero et al. 2002, Gandini et al. 1999, Gellatt et al. 2007, Hucke-Gaete et al. 2006, MacLeod et al. 2007, Ozturk et al. 2007, Pinto et al. 2006, Raga et al. 2006, Rodway and Montevecchi 1996, Santos and Pierce 2003, Sanger 1987, Scolaro et al. 1999, Silva 1999, Springer 1986, Spitz et al. 2007, Suryan 2000, Tonay 2007, Trites et al. 2007, Vanda et al. 2001, Wanless et al. 2004, Watwood et al. 2006, Winship and Trites 2003

Wetjens Dimmlich

Freshly caught sardines

OVEREXPLOITED PREY SPECIES

Fisheries targeting prey species have grown dramatically during the past century and are currently overdrawn, leaving predators with depleted food supplies. Early fisheries targeted only herring, sardines, and menhaden until expanding to meet the demand for cheap animal feed after World War II, and the more recent demand from carnivorous aquaculture (IFFO 2006a, Alder and Pauly 2006, Watson et al. 2006). Now more than 88 different prey stocks are caught everywhere from the tropics to the poles (FAO).

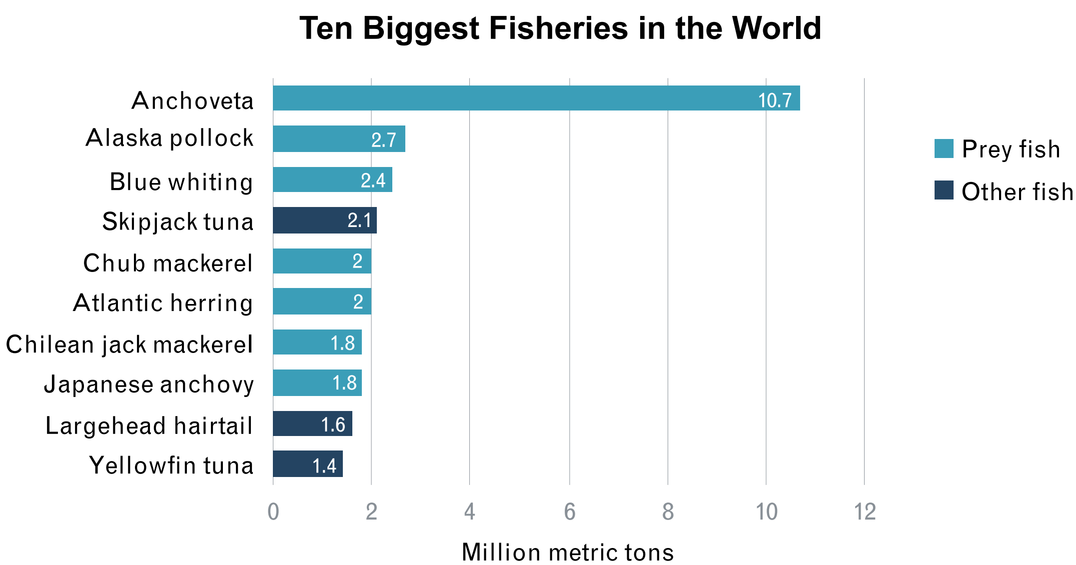


FIGURE 2. Ten Biggest Fisheries in the World
Source: FAO 2006

Prey species have become targets for the largest fisheries in the world, as populations of the bigger fish in the sea are exhausted (Jackson 2008, Pauly et al. 1998). Seven of the top ten fisheries rely on prey fish, as illustrated in Figure 2, and today's landings of prey fish are more than four times those of 1950 (FAO). More than 10 million metric tons of anchoveta alone are removed from the ocean every year, made unavailable as prey to seabirds, mammals, and predatory fish.

Squid fishing

ANONYMOUS FISH

Prey are known by many names, in part because they are usually overlooked. Some are accurate yet vague, including "small pelagics" indicating that they are found in open water, or "schooling fish." Others such as "bait fish," "forage fish," and "prey fish" define them by their uses and fail to include non-fish species like squid and krill.

Horeal Vidal Sabatte

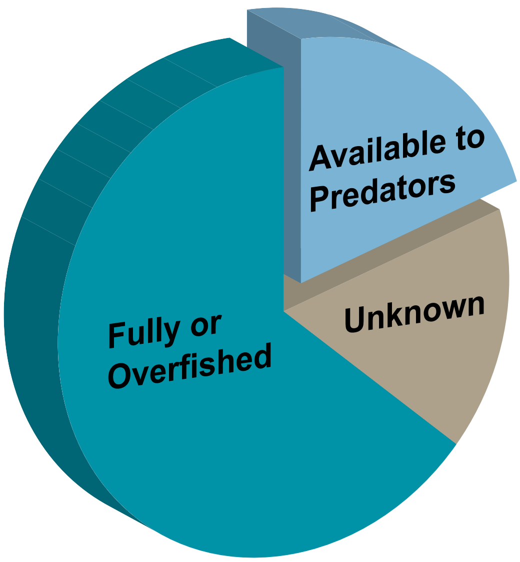


FIGURE 3. Prey Stocks that are Fully or Overfished
Source: Percentage of 88 assessed stocks from FAO 2005

Decades of intense fishing pressure have taken their toll. Among the stocks assessed by the FAO, the majority are fully or overexploited with no regard for predator needs (2005). For an additional 16 percent, their status is unknown and yet fishing continues. This leaves only 20 percent of currently fished prey populations with any potential to sustain natural predators (see Figure 3). Even fewer of these populations remain large enough to support growing pressures from fisheries, aquaculture, and climate change.

According to the United Nations Food and Agricultural Organization, all prey fisheries in the Southeast Pacific are between fully and overexploited, with the exception of squid. The fishery for sardina del Norte (*Sardinops sagax*) peaked in the mid-1980s before crashing to less than one percent of peak landings with no sign of recovery. Nearly all fisheries for prey in the North Atlantic, Central Atlantic, and North Pacific are fully exploited with no consideration for predators. This includes menhaden along the US coast, sand eels in Europe, and California market squid (*Loligo opalescens*).

THREATS: OVERFISHING

Prey fish are taken for granted in fisheries management, despite their critical role in marine food webs. Even in planning the recovery of endangered or overfished species, managers often give no consideration of the food supply needed for their populations to rebound. Squid, krill, and other prey remain ignored, unregulated and unaccounted for.

Disrupted Schooling Behavior

Schooling fish and “bait balls” protect individual fish from natural predators, and schools are also formed during spawning to increase the chances of future generations. Schooling prey are so important to tuna, whales, and other long-lived animals that they drive predator migrations, breeding, and nursing.

Unfortunately, schooling prey fish are easy targets for large nets (Alder et al. 2008, Watson et al. 2006) and can be quickly depleted or dispersed. Predators are forced to compete with industrial fishing vessels, and are sometimes captured incidentally while feeding on schools of fish.


Gordon Stroupe

Schooling prey fish surround a Sand Tiger Shark

Prey remain under the radar, unregulated and unaccounted for.

Boom and Bust Populations

Many prey species have short life spans. As a result, some prey species are known for dramatic boom and bust cycles from year to year (Alder et al. 2008), often because an entire generation of fish or squid fails to make it to adulthood. Changes in the prevailing currents or temperature may sweep away newly hatched eggs and larvae (Chavez et al. 2003), or major weather events such as hurricanes can wipe out an entire generation of larval fish. In some cases, population crashes can be linked to particular events including oil spills or pollution (Peterson et al. 2003, Paine et al. 1996).

Overfishing can also drive population crashes by removing juveniles before they are old enough to reproduce, or by directly removing spawning adults. Population crashes may also be caused by increased competition or predation by other species in the food web. All of these factors combine over short periods of time to make it extremely difficult to predict prey availability.

Localized Depletion

Many predators depend on their prey to be available at a particular place and time. Depletion of prey populations in one local area can be extremely disruptive to their predators, even if distant populations remain strong (Furness and Tasker 2000). For example, during nesting season, seabirds have a very limited time away from their young to find food and return. If there are not enough prey where and when the birds expect, both chicks and parents are at risk for starvation or death (Hunt and Furness 1996).

Coastal communities and fishermen are also tied to a particular place and season to make their living. In North Carolina and in New England, bluefin tuna fishing depends on tuna arriving during the legal fishing season and staying as long as possible. When the herring is gone, hungry tuna may move on prematurely and the fishermen return empty-handed.

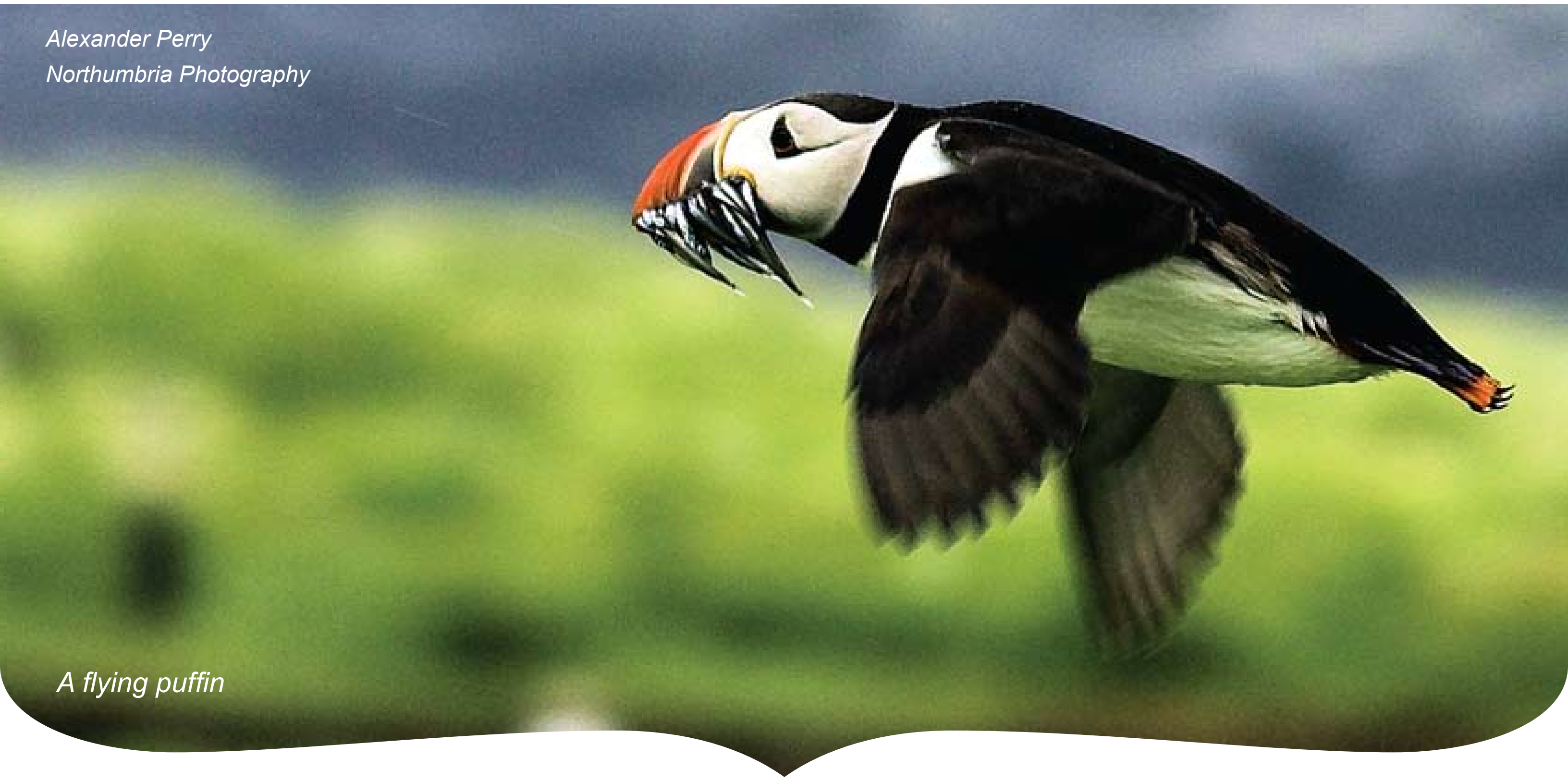
Predators and Natural Mortality

When no information is available on how much ocean predators consume, their needs are arbitrarily assumed to be low. Standard fishery models gloss over the needs of ocean predators in a single number known as "natural mortality" which is often flawed.

For example, recent analysis found that marine mammals and large fish are actually eating four times as many herring than assumed by the official government assessment (Read and Brownstein 2003). In failing to account for these predators, the typical approach overestimates the amount of fishing that can be sustained by their prey. For years we have been catching many more prey fish than can sustain both human fisheries and predators.

Shifting Baselines

Our current management framework assumes ecosystems with very low levels of natural predation. Large predatory fish have been overexploited and the legacy of whaling and depleted marine mammal populations remains. Ironically, as predatory fish recover and reclaim their share of prey species, we blame them for eating too much. In the Chesapeake Bay, some ask whether there will be enough menhaden left as striped bass recover. In the time that striped bass have been absent due to overfishing, human fishing has expanded - removing their prey.



Alexander Perry
Northumbria Photography

A flying puffin

For years we have been fishing on a deficit.

THREATS: AQUACULTURE

Increasingly, the driver behind overfishing of prey species is aquaculture. Salmon, tuna, and other high-value farmed fish are the fastest growing seafood products in the world (Delgado et al. 2003). As a result, an increasing number of new aquaculture operations specialize in fish that eat fish, which require constant supplies of high-calorie feed.

Aquaculture currently consumes more than 81 percent of the prey fish captured and "reduced" to fish oil, and approximately half of those captured for fishmeal (Tacon et al. 2006). The remaining prey fish are used in agriculture and to a lesser degree pet food and pharmaceuticals (Figure 4; Tacon et al. 2006, Delgado et al. 2003, Campbell and Alder 2006, FIN 2007a).

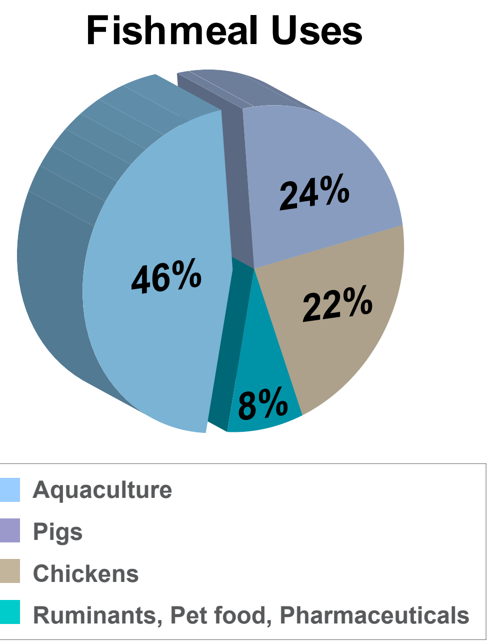


FIGURE 4. Fishmeal Consumption
Source: Data from Campbell and Alder 2008

Delta Aquaculture Equipment Co.

A third of all global fish landings are destined for fish meal and oil each year, caught mostly in dedicated reduction fisheries (Watson et al. 2006, FIN 2007b, IFFO 2006a, New and Wijkstrom, 2002). These fish are pressed, dried, and milled into concentrated fish oil and brown powder called fishmeal. A smaller percentage of fish meal is derived from byproducts of fish processing (FIN 2007b), and an unknown percentage is derived from unreported or illegal bycatch (Alder et al. 2008, Tuominen and Esmark 2003).

Among farmed fish, salmon consume more fish oil than all other aquaculture operations combined. In 2003, salmon pens alone consumed 51 percent of world fish oil and 19 percent of world fishmeal supplies respectively (FIN 2007b). In fact, the astronomical growth and success of Chile's salmon aquaculture industry is made possible by readily available fish oil supplies produced within the country (Campbell and Alder 2006). For salmon aquaculture, an estimated four to eleven pounds of prey fish are consumed to grow only one pound of farmed salmon (Fishmeal Information Network, Buschmann et al. 2006).

Further growth of the aquaculture industry is limited by the price of aquafeeds (Tuominen and Esmark 2003, Delgado et al. 2003, New and Wijkstrom 2002). Prices for fish oil and meal are expected to increase and will be highest when natural population cycles lead to diminished forage fish catches, creating powerful incentives for overfishing (Delgado et al. 2003).

2020 The year aquaculture outgrows the supply of fishmeal

— New and Wijkstrom, 2002

Cristián Gutiérrez / Oceana

Eric Cheng

Shoveling prey fish into net pens to feed farmed tuna

TUNA FATTENING

Tuna fattening has expanded in response to continued demand for full-grown bluefin tuna despite reduced supply due to overfishing. Juvenile bluefin are captured and held for varying lengths of time in net pens in Mexico, Canada, Australia, Japan, and throughout the Mediterranean (Ottolenghi et al. 2004, Volpe 2005). They are fed with frozen prey fish and later sold on the international market for sushi and sashimi, particularly in Japan and Korea.

Bluefin tuna are voracious predators, and require between two and ten percent of their body weight in prey fish every day of the peak summer season (Lovatelli 2003). This results in an estimated 225,000 metric tons of prey fish thrown into the Mediterranean tuna pens alone each year (Tudela et al. 2005).

Industry growth is limited by the supply of prey fish, and Mediterranean fattening operations already import 95 percent of the prey fish, mostly frozen sardines (Lovatelli 2003, Ottolenghi et al. 2004, Volpe 2005). In Mexico, more than half the catch of Pacific sardines is delivered directly to nearby tuna fattening pens, and much of the remaining catch is frozen or converted to fishmeal for use in other aquaculture operations. (Zertuche-González et al. 2008).

Steve Johnson

A puffin and an Arctic tern compete for prey

THREATS: CLIMATE CHANGE

Ocean predators are expected to suffer a wide range of impacts from global climate change, making them even more vulnerable to prey shortages. At the same time, climate change is also likely to affect prey species populations with changing temperatures, ocean currents, and sea ice.

Rising Temperatures

Prey fish and the food webs they support are highly sensitive to temperature changes, as seen in their dramatic population changes during El Niño and decade-long climate shifts (Anderson and Piatt 1999, Chavez et al. 2003). Small fish require favorable currents and temperatures to escape predators and to find enough to eat. The largest fishery in the world is vulnerable when warm El Niño waters bring Peruvian anchoveta toward the coast where they can be more easily caught. In 1972 this fishery crashed dramatically when heavy fishing coincided with an El Niño year (Clark 1976).

At the height of a 1950s cold period, temperature combined with heavy fishing to precipitate the collapse of the California sardine fishery made famous by John Steinbeck in his novel Cannery Row. Gulf of Alaska food webs are also tuned to temperature, and preferred prey such as capelin become scarce during warm periods, forcing marine mammals and seabirds to less nutritious options (Anderson and Piatt 1999). These prey shortages provide a preview of the likely effects of global warming.

Warm water in the North Sea brings fewer and smaller sand eels, the dominant prey for harbor porpoises (*Phocoena phocoena*), and could cause sand eels to hatch too soon for critical spring feeding time. Over the last thirty years, porpoises have suffered a 27 percent increase in starvation rates as sand eel populations shrink (Wanless et al. 2004, MacLeod et al. 2007a, 2007b). These climate-driven prey shortages are even more acute when prey populations are already overfished.

John Rix / Fathom This Underwater Productions

SEABIRDS AT RISK

Seabird populations are highly sensitive to their food supply, and increasingly threatened by human over-exploitation of prey fish. Crashes in fish populations in general have historically coincided with catastrophic seabird breeding failures, and climate-driven prey shortages may hit seabirds hardest.

When prey goes missing, seabirds rely on less nutritious alternatives and may become weak, delay their breeding season, and spend more time away from the nest searching for food (LeMaho et al. 1993). During herring declines in Norway's Lofoten Islands, the number of puffin burrows with chicks declined by 64 percent in the 1980s (Wright et al. 1996). Emaciated murres washed up on Norwegian shores after years of heavy fishing on capelin stocks, as populations of this usually common seabird plummeted by 56 to 80 percent (Hunt and Byrd 1999). In the eastern Bering Sea, both kittiwakes and murres starved to death during two decades of pollock shortages (Hunt and Byrd 1999, Springer et al. 1986).

Christopher Michel

Sea Ice

Polar predators and prey are under threat as the sea ice begins to melt (Smetacek and Nicol 2005, ACIA 2005). Krill aggregations feed on algae in a hidden sea ice ecosystem (Lizotte 2001, Loeb et al. 1997, Marschall 1988). As melting sea ice makes life harder in other ways, krill aggregations will shrink and in turn leave hungry penguins, whales, fish, and albatrosses in a weakened state. Warming and the decline of Antarctic krill have already been linked to reduced calving success of southern right whales that feed on this popular prey (Leaper et al. 2006)

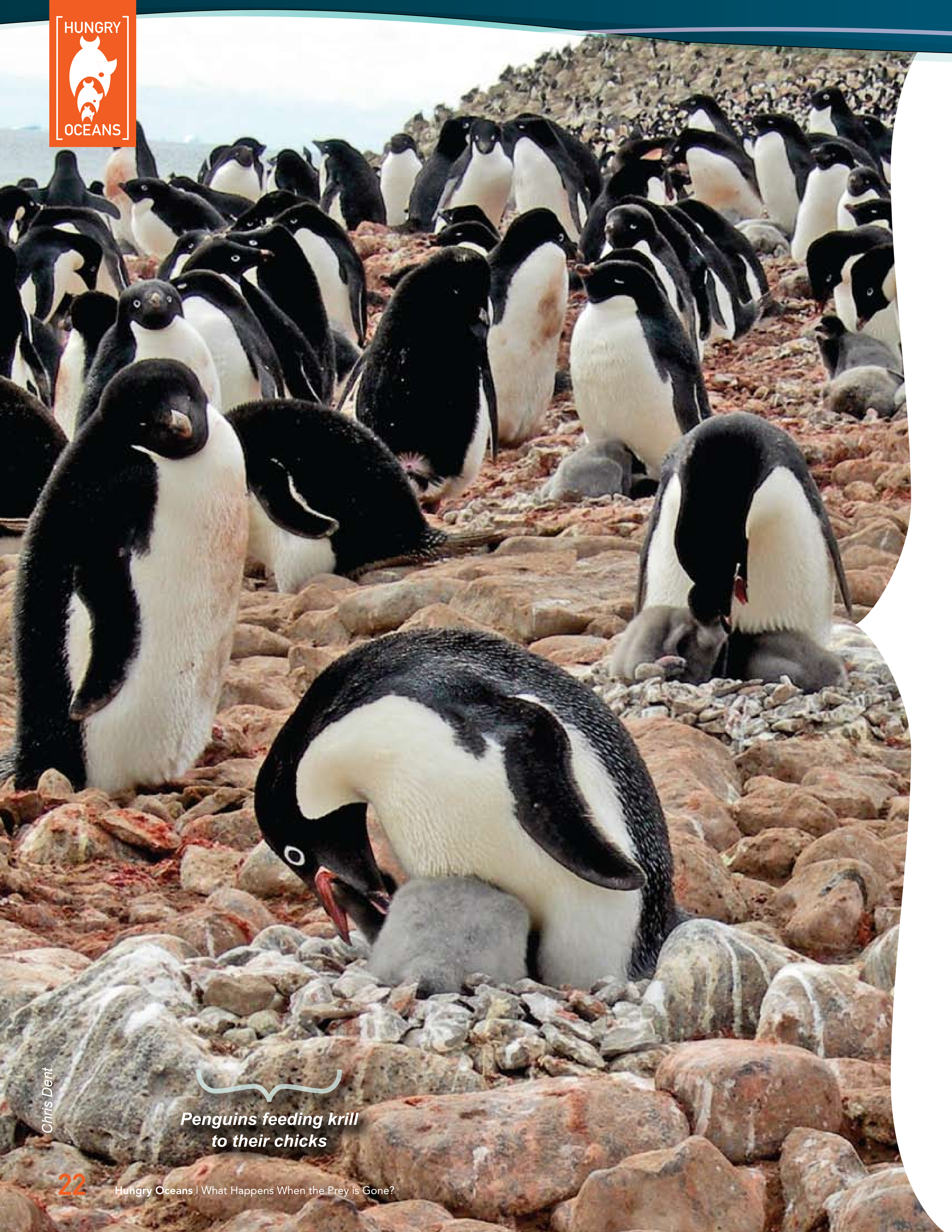
Arctic predators are also threatened by the loss of sea ice and their prey, including narwhals, ringed seals, ivory gulls, and Atlantic salmon. Their favorite foods include Arctic cod (*Boreogadus saida*), which hides in ice cracks and channels and feeds on tiny organisms in the associated ecosystem (Bluhm and Gradinger 2008, Gradinger and Bluhm 2002, Tynan and DeMaster 1997).

Geographic Range Shifts

As ocean temperatures and currents are altered by climate change, the geographic ranges for predators and their prey are expected to move poleward. Wild Pacific salmon are predicted to shift northward, and sockeye salmon could shift entirely into the Bering Sea within the next 50 years (Welch et al. 1998, Mote et al. 2003). While some populations may adapt to their new location, others will likely suffer prey shortages. Salmon will be forced to seek out different prey, which may be less abundant in their new surroundings, leaving them malnourished and less able to adapt to other climate stresses (Bilby et al. 2007).

Wetjens Dimmlich

Despite their name, Crabeater seals primarily eat krill



Penguins feeding krill to their chicks

SOLUTIONS: GETTING STARTED

Despite the alarming global outlook, some progress has been made toward the evaluation and management of prey species with predator needs in mind, as highlighted below. Successful management of predator-prey relations is an important first step toward ecosystem-based management, and must include prohibiting new fisheries for prey species, setting conservative catch limits for existing fisheries, prioritizing uses of prey species, and anticipating and reducing fishing during prey declines.

Manage for Ecosystem Integrity

Protecting prey is fundamental to keeping ocean ecosystems intact. State, regional, and federal agencies in the U.S. are beginning to recognize that healthy prey populations should be a goal for fishery managers. Yet initial efforts have devoted a disproportionate amount of time to gathering background information, with minimal actions toward preventing the actual loss of prey populations. Catch levels need to be set with large predatory fish, marine mammals, sea birds, and other marine life in mind.

The U.S. federal government is taking steps toward appropriate management of prey species. In 2002, federal regulations identified prey as a component of essential fish habitat and recognized the loss of prey as a problem for fisheries. More recently, regional fishery management councils have begun food web modeling with implicit consideration of predator needs.

States are also recognizing the importance of prey species. Most notably, Washington State was one of the first to create a dedicated management plan for forage fish and to explicitly adopt the protection of prey and "the integrity of the ecosystem and habitat upon which marine resources depend" as a goal for the Washington Department of Fish and Wildlife. Washington's plan identifies knowledge gaps, addresses commercial and recreational catches, and describes the ecological role of prey fish. Along with Oregon and California, Washington has also banned fishing for krill, an important prey species. However, many states lag behind and in states with existing plans, management actions are urgently needed to actively protect prey fish.

Aziz T. Saltik

Salvin's Albatross

Pablo Andrés Cáceres Contreras

No New Fisheries for Prey Species

The most conservative approach to protecting prey is to ban fishing on these species before it begins. In 1998, the federal government banned fishing for prey species except pollock in federal waters around Alaska. The North Pacific Fishery Management Council and NOAA Fisheries acted to protect valuable groundfish and salmon predators targeted by fisheries, as well as other predators such as whales, sea lions, and albatrosses. The prey or "forage fish" protected from being caught included entire families of species such as krill (Euphausiacea), capelin and smelts (Osmeridae), sand lance (Ammodytidae) and many others.

Fishing for krill will likely similarly be banned in federal waters of the West Coast of the United States. The Pacific Fishery Management Council and NOAA Fisheries created a prohibited harvest species category to "ensure the long-term health and productivity of the West Coast ecosystem." This proposed federal ban reinforces state bans on krill fishing established in California, Oregon, and Washington to prevent future exploitation of this important prey.

Set Conservative Catch Limits

Where fisheries on prey species already exist, conservative catch limits and careful monitoring are essential to prevent harm to natural predators. Squid, krill, and other prey fisheries sometimes remain unregulated or have incomplete management plans because they are not recognized as important.

Early management of Antarctic krill by the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) exemplifies the conservative catch limits needed for prey species. With the ecosystem explicitly in mind, CCAMLR set initial catch limits for krill at nearly half the level of fishing mortality typically chosen for fisheries elsewhere in the world. Although there is substantial concern that this level is still too high, not fishing to the limit is an important start toward true ecosystem-based management.

Atlantic cod stocks have seen severe declines in recent decades and have yet to recover despite drastic cutbacks in fishing by the Canadian fleet (DFO 2005). Cod in the Northern Gulf of St. Lawrence also appear to be "starving to death" for unknown reasons which may include shortages of capelin, a preferred prey (DFO 2008, 2006). Conservative catch limits for capelin are an important component of Canada's recovery strategy for cod populations in Newfoundland and Labrador (DFO 2006, 2005).

Carlos Minguell

"To keep every cog and wheel is the first precaution of intelligent tinkering."

— Aldo Leopold

Prioritize Uses for Prey

In addition to setting conservative catch levels, managers should give predators top priority before we divide up their prey, to better ensure that prey species fisheries are managed for the long-term health of the ecosystem. This includes specific assessment and allocation for the ecosystem - for fish, invertebrates, marine mammals, sea turtles, and other marine life.

After predator needs have been met, catches of prey species should be destined for direct human consumption. These small, fast-growing fish can reliably serve as primary protein for people. Peruvians have seen an upswing in anchoveta consumption since a 2006 event featuring top chef Gastón Acurio, scientist Patricia Majluf, and 18,000 diners feasting on flavorful fish that are more typically ground up for animal feed (Jacquet 2007).

Historically, direct consumption has been prioritized over use for bait, aquaculture, and other activities. California's legislature in 1920 prohibited converting fish into oil and meal that would otherwise be fit for human consumption (Watson et al. 2006). The European Union later banned the use of Atlantic herring in fish meal in 2003, and England banned the use of fishmeal in ruminant feed due to concern over mad cow disease (Josupeit 2006, 2007). Peru banned the reduction of certain fish into oil and meal, including the South American pilchard (*Sardinops sagax*) and jurel or horse mackerel (*Trachurus murphyi*) (Watson et al. 2006).

Bait fish plays an important role in recreational and commercial fisheries, and should be prioritized after ecosystem and human needs. Aquaculture, animal feed, and all other uses for prey fish compete for these higher priority uses and require explicit acknowledgement and careful control. As aquaculture drives up prices for fishmeal and oil, prey fish now used for human consumption in developing regions are being diverted to industrial processing, with ethical implications (Alder and Pauly, 2006, FAO 2006, Delgado et al. 2003).

Fish Less During Natural Declines

Many prey species boom and bust with ocean temperature cycles, particularly sardines and anchovies. While it is normal for these populations to drop in response to changing conditions, heavy fishing during less productive phases could prevent the population from rebounding when favorable conditions return.

In the U.S., the Pacific Fishery Management Council is one of the first management organizations to explicitly account for the influence of ocean temperature cycles on sardines. This Council adopted a rule for managing Pacific sardine that adjusts the number of fish that can be caught according to sea surface temperature. Pacific sardines reproduce more slowly when the ocean is cooler, and fewer fish can be caught during this vulnerable time.

Sardines ready for human consumption

Cathou Cathare

An Arctic tern catches its next meal

Paul McDonnell

SOLUTIONS: LOOKING AHEAD

While the needs of natural predators are increasingly recognized in public policy, concrete management actions to protect them are still generally lacking. However, several emerging science-based approaches could improve management of prey species substantially.

Maintain a Reserve for Natural Predators

Quantitative food requirements for each predator group are increasingly becoming available (Read and Brownstein 2003, Hunt and Furness 1996, Field and Francis 2006). Prey reserves can now be set aside for natural predators when catch limits are set for prey fish, squid, and krill.

At the stock assessment level, the needs of predators should be more rigorously accounted for in estimates of natural mortality and the definition of optimum yield for fisheries. At the policy and management level, explicit allocations can be made for ecosystem needs or for natural predators.

Wetjens Dimmlich

Female elephant seal and pup

Protect Breeding Hotspots

For predators with clear needs for prey during spawning, nursing, or nesting season, closures on fishing for squid, anchovy, or other prey may be appropriate. This would prohibit fishing in very specific times and places to increase prey availability and reproductive success with the added benefit of reducing the number of predators caught in the nets. Unfortunately the specific needs of many predators remain unknown.

In Punta Tombo, Argentina, tracking experiments with Magellanic penguins clearly show their most important foraging areas in need of protection (Boersma 2008). In the North Sea, fishing activity and seabird feeding are concentrated in different locations suggesting the potential for successful zoning (Furness and Tasker 2000, Hunt and Furness 1996). Separating fishing from seabird feeding could minimize fishery impacts and prevent localized depletion of prey.

Save 10% for Climate Losses

In addition to planning for ecosystem needs, managers should leave a buffer for climate-driven losses in prey populations. In the absence of more quantitative decision rules based on temperature, managers should insure against climate change impacts with a reduction of ten percent in catch limits.

Manage in Real Time

Real-time monitoring during the fishing season is especially helpful for management of short-lived and infrequently counted prey fish and invertebrates. Daily updates on catch and effort for each vessel allow managers to monitor the status of the fishery and decide whether too many fish have been taken in a season. Real-time monitoring is currently active for the squid (*Loligo gahi*) fishery in the Falkland Islands and has been proposed for United States squid fisheries (Agnew et al. 1998). Real-time monitoring of fishing intensity has also been proposed to protect Peruvian anchoveta, which are more vulnerable to being caught as they move closer to shore during El Niño climate cycles (Bertrand et al. 2005).

SOLUTIONS SUMMARY

GOAL:

Protect prey species as fundamental to ocean ecosystems and fisheries.

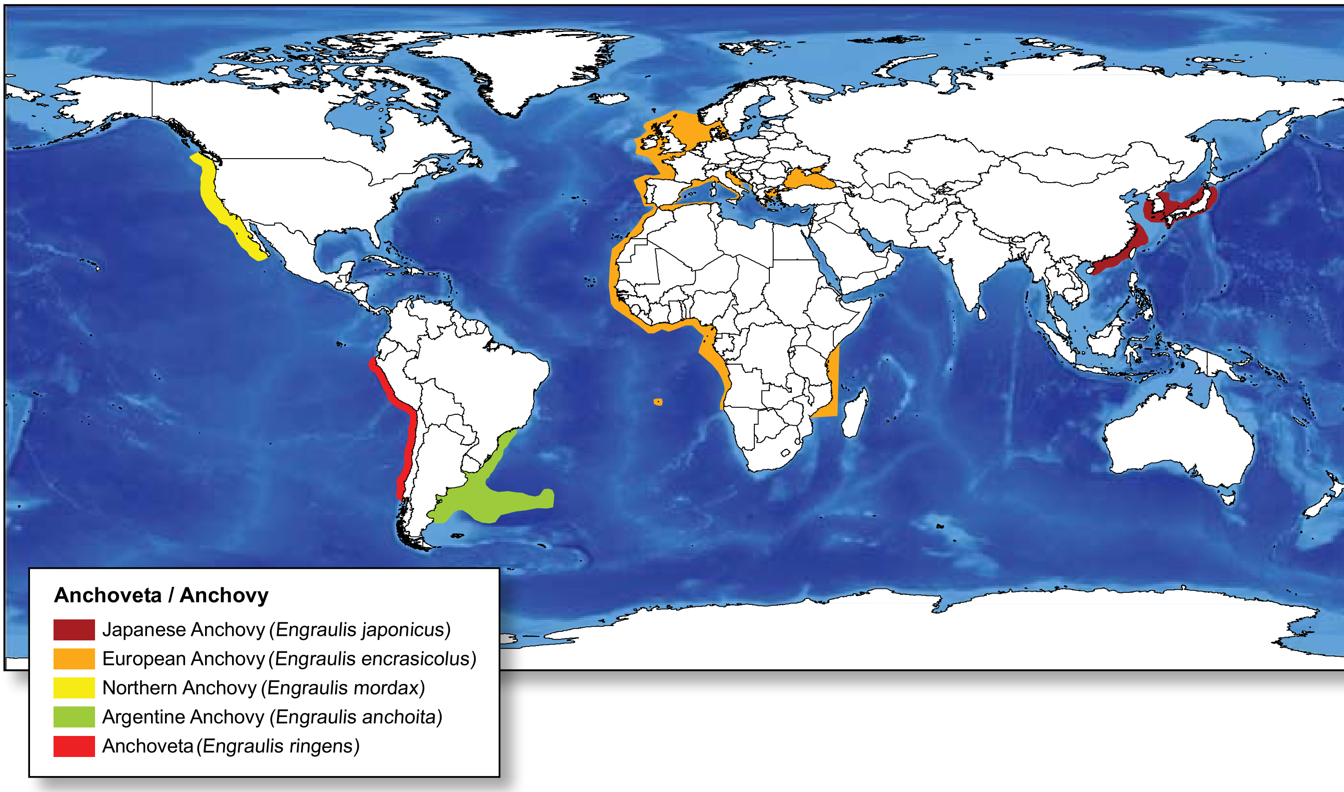
SOLUTIONS:

1. No new fisheries for prey
2. Set conservative limits for prey fisheries and save 10 percent for climate impacts
3. Protect breeding hotspots
4. Prioritize uses for prey—place ecosystem needs first

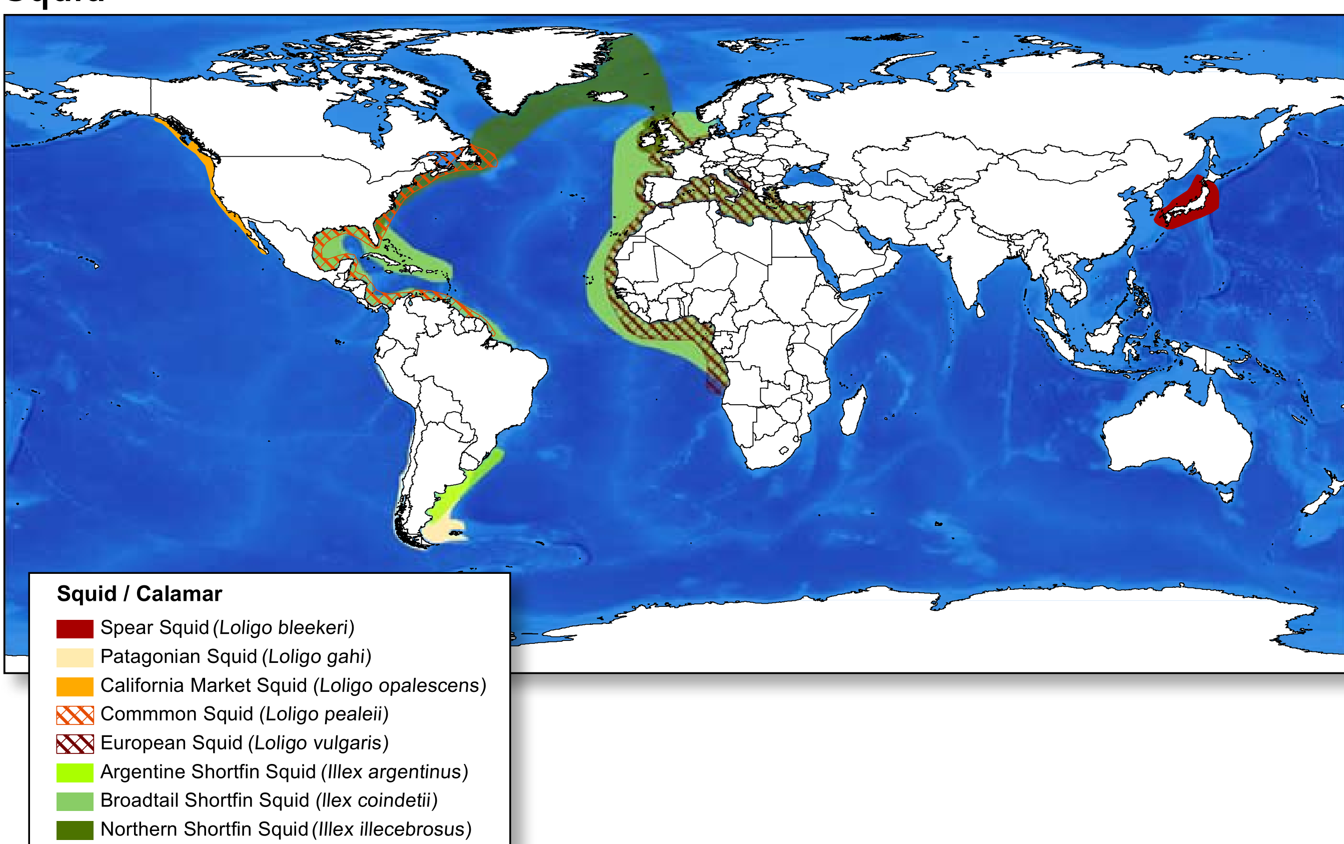
Bryant Austin

PREY SPECIES AROUND THE WORLD

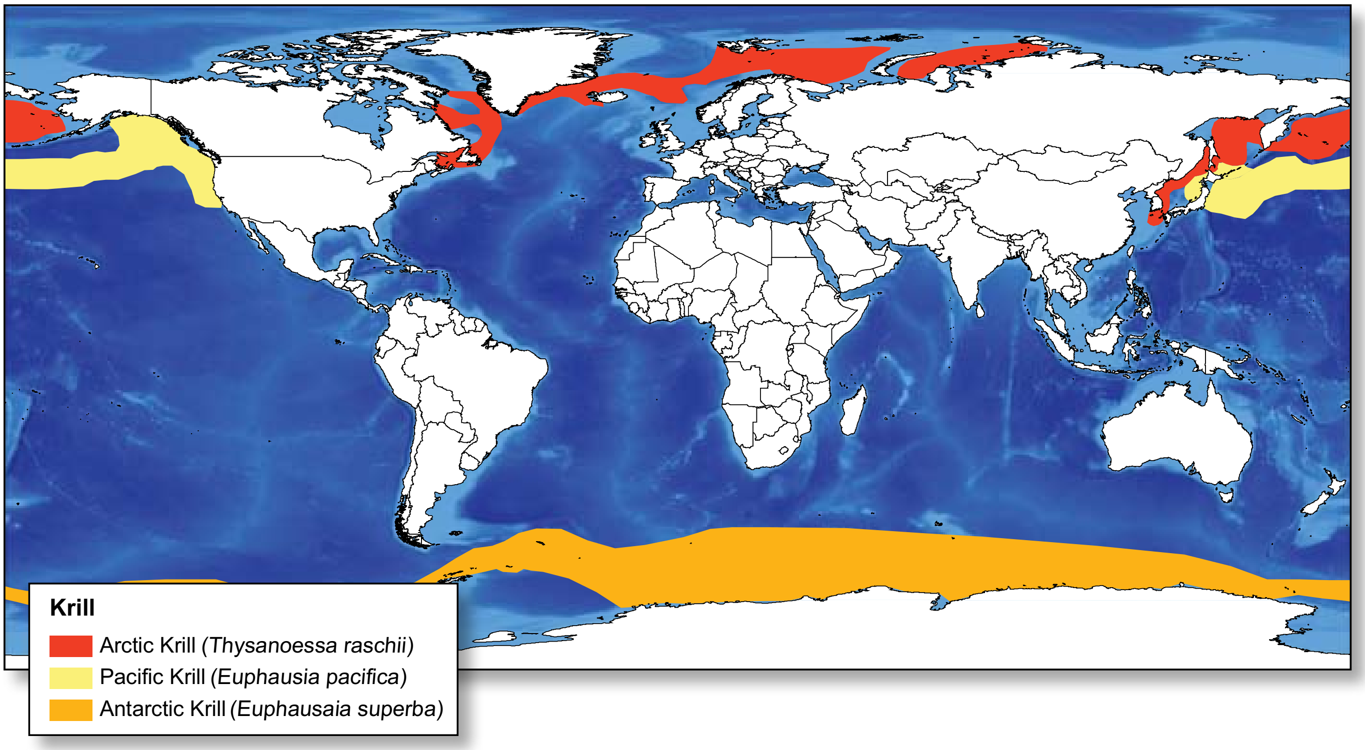
Anchovy



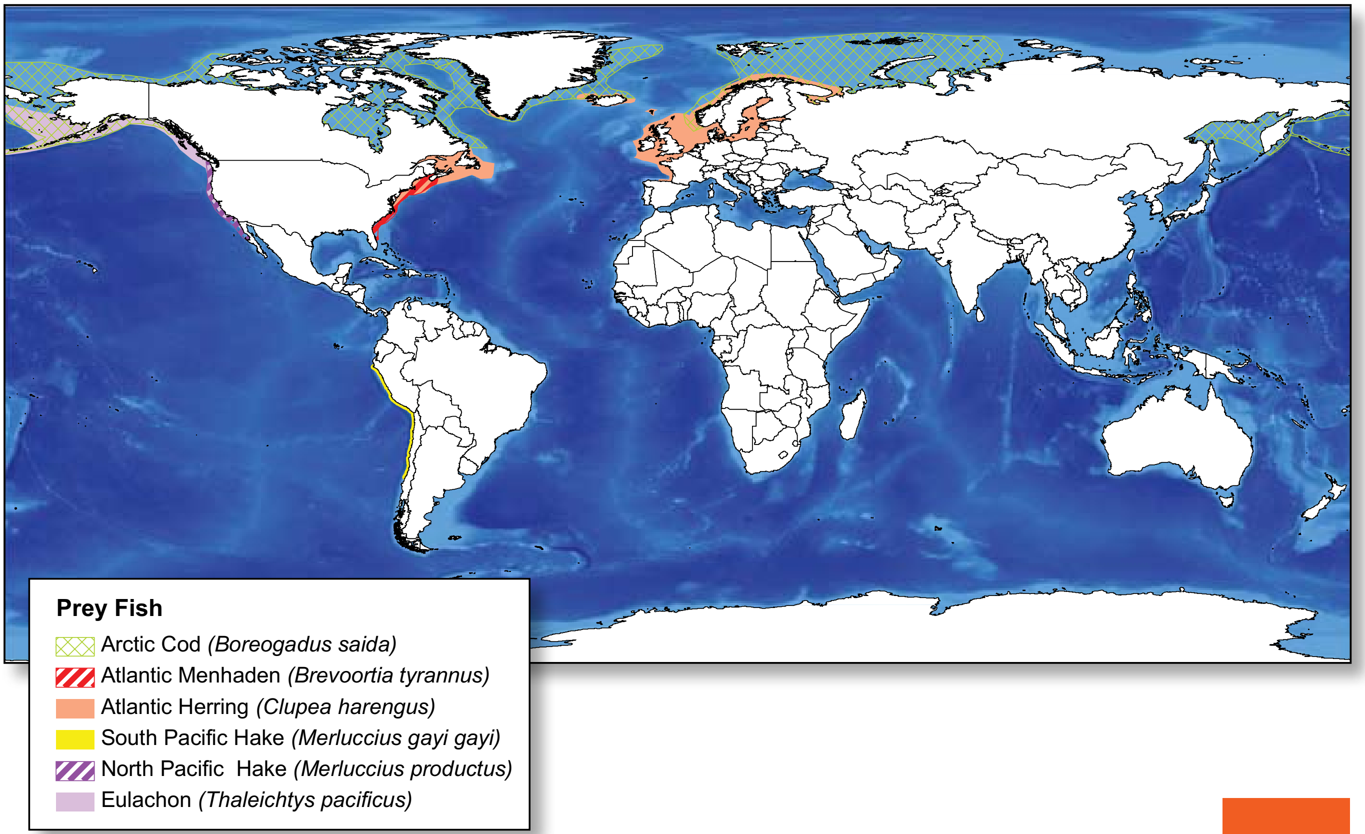
Squid



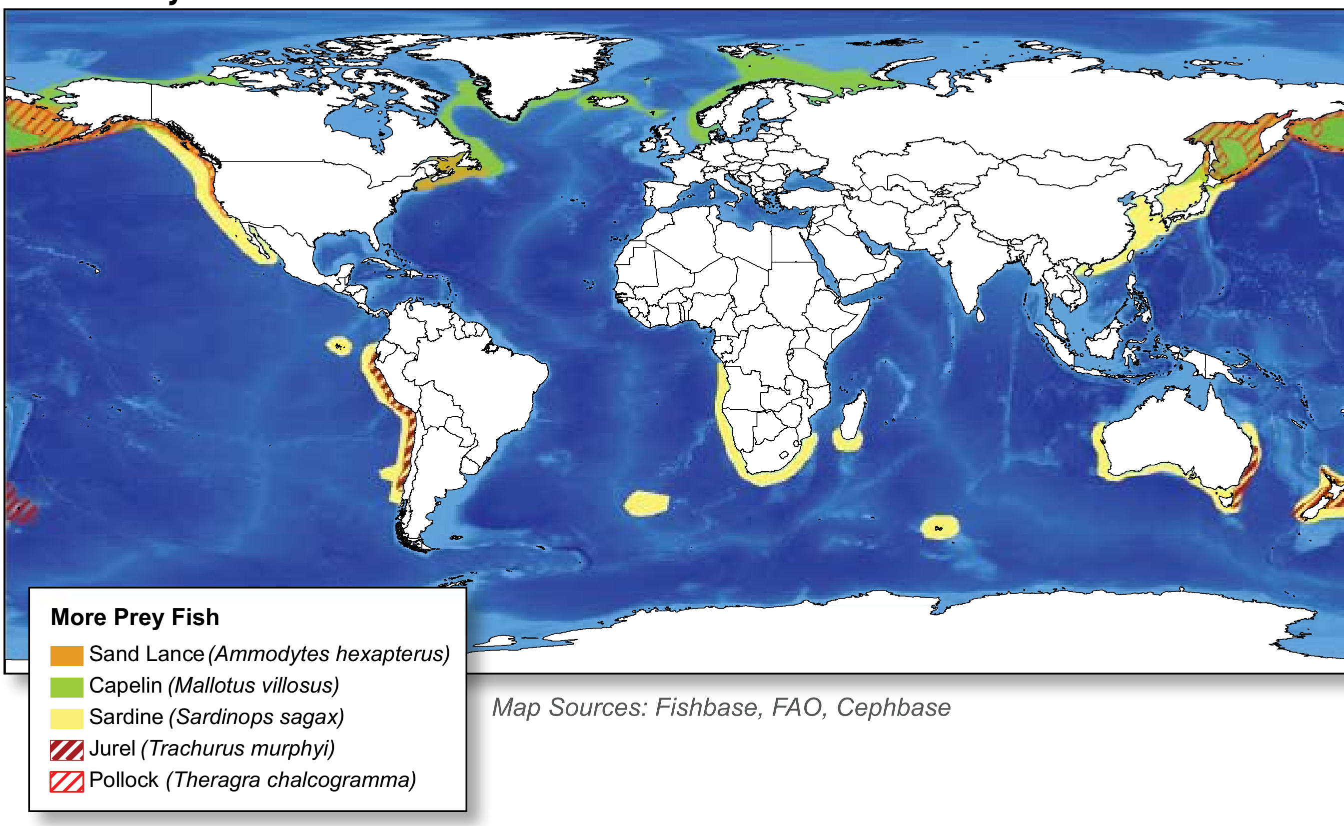
Krill



Prey Fish



More Prey Fish



Map Sources: Fishbase, FAO, Cephbase

Dolphins and bait ball

Colin Robson

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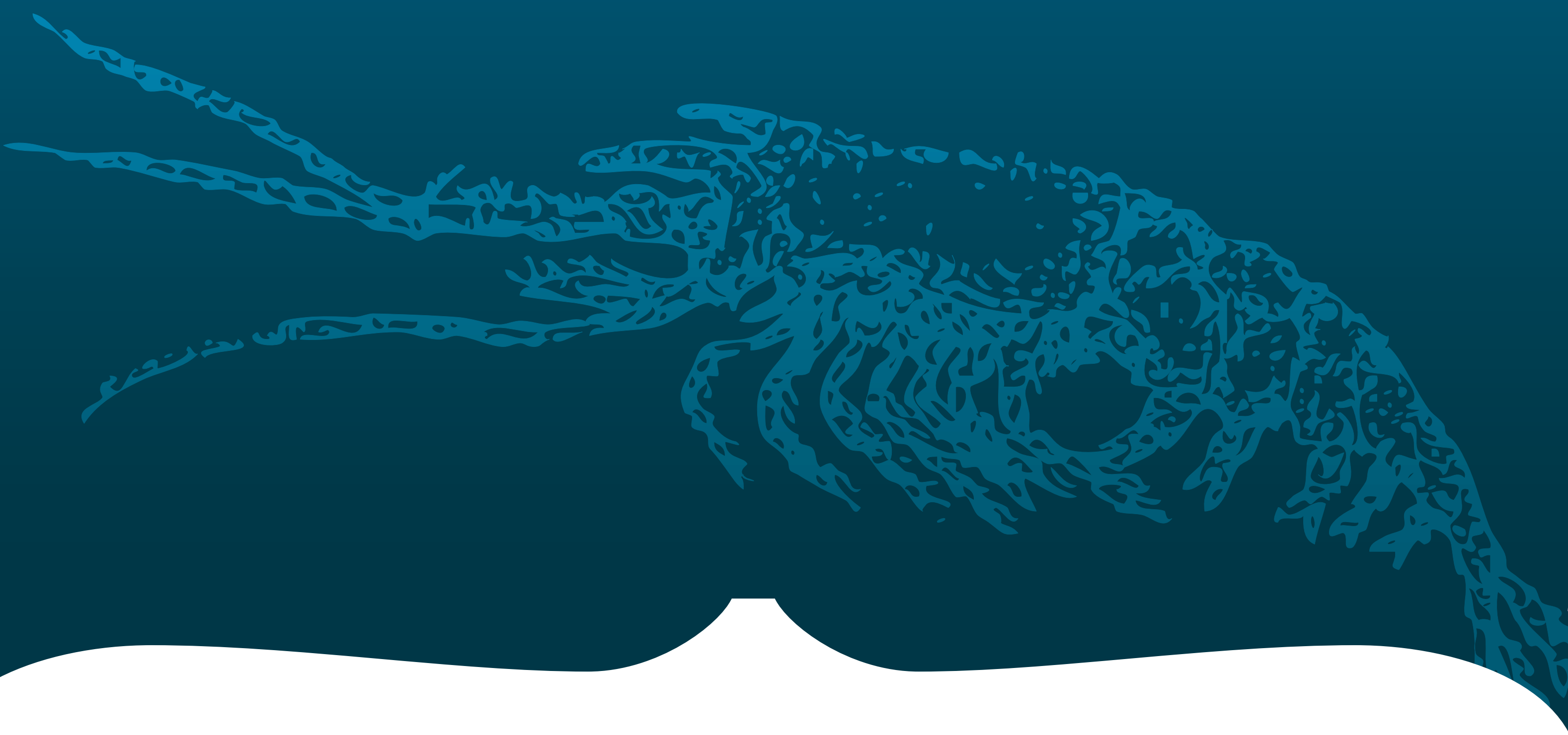

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