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REPORT

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2018

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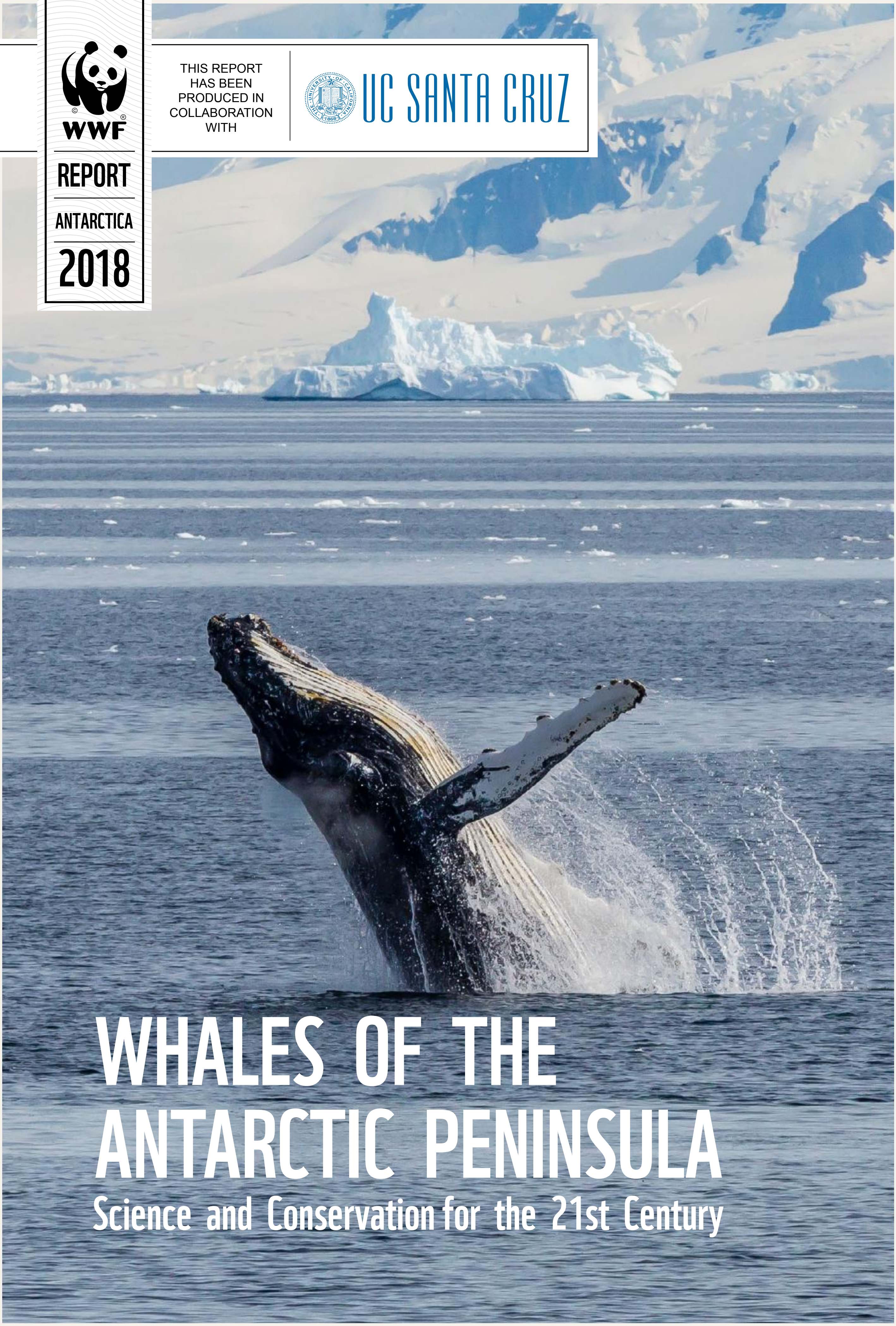

WHALES OF THE ANTARCTIC PENINSULA

Science and Conservation for the 21st Century

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WWF's mission is to stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature, by: conserving the world's biological diversity, ensuring that the use of renewable natural resources is sustainable, and promoting the reduction of pollution and wasteful consumption.

The WWF Antarctic Programme works to safeguard a thriving wild Antarctica with a diversity of life for future generations. Collaborating with individuals, NGOs, governments, industry and science bodies, we monitor and report on the state of species, ecosystems and human impacts to co-design and communicate urgent solutions.

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WHALES
OF THE ANTARCTIC PENINSULA

KEY MESSAGES

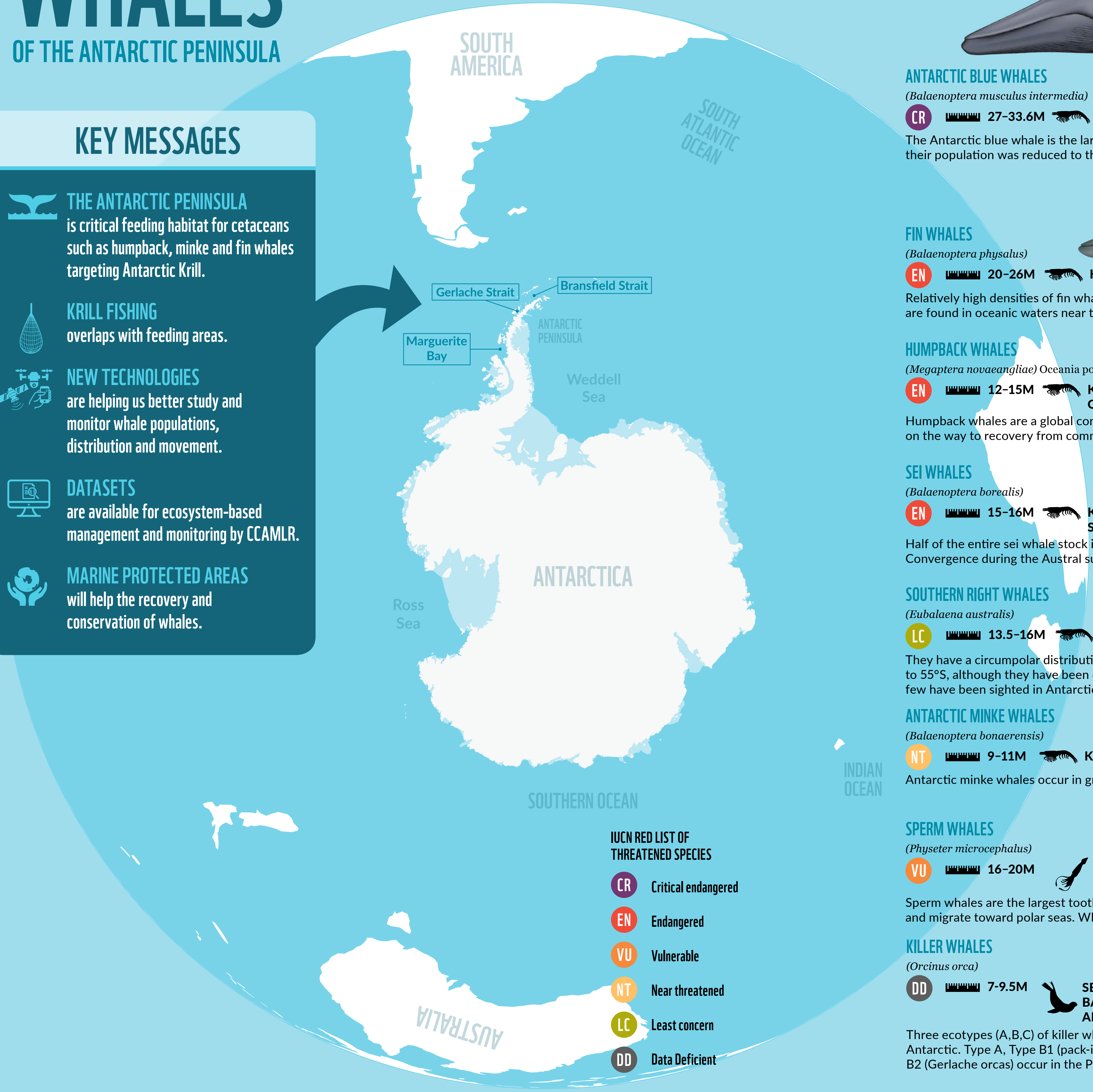
THE ANTARCTIC PENINSULA is critical feeding habitat for cetaceans such as humpback, minke and fin whales targeting Antarctic Krill.

KRILL FISHING overlaps with feeding areas.

NEW TECHNOLOGIES are helping us better study and monitor whale populations, distribution and movement.

DATASETS are available for ecosystem-based management and monitoring by CCAMLR.

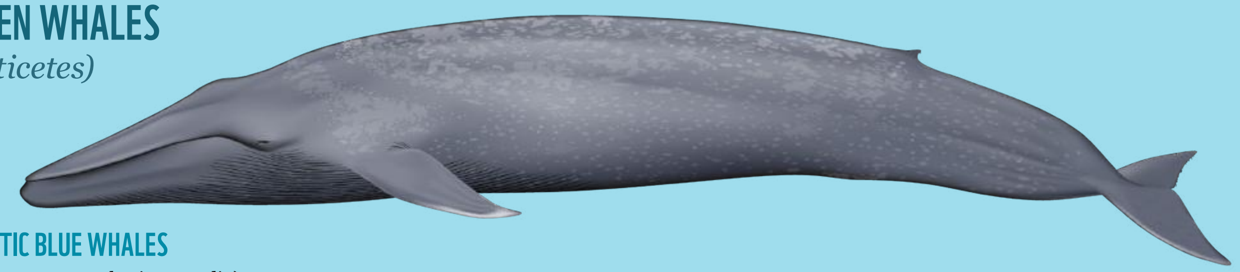
MARINE PROTECTED AREAS will help the recovery and conservation of whales.



IUCN RED LIST OF THREATENED SPECIES

- CR Critical endangered
- EN Endangered
- VU Vulnerable
- NT Near threatened
- LC Least concern
- DD Data Deficient

BALEEN WHALES
(Mysticetes)

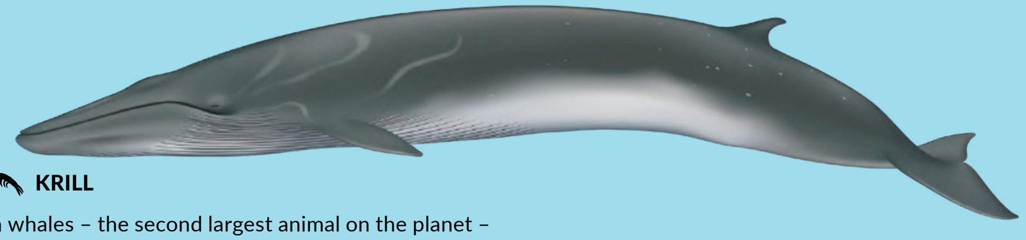


ANTARCTIC BLUE WHALES
(Balaenoptera musculus intermedia)

CR | 27–33.6M | KRILL

The Antarctic blue whale is the largest animal on earth. Due to whaling in the 20th century, their population was reduced to the brink of extinction.[10,11]

(1.75m)



FIN WHALES
(Balaenoptera physalus)

EN | 20–26M | KRILL

Relatively high densities of fin whales – the second largest animal on the planet – are found in oceanic waters near the South Shetland Islands.[13,14]

HUMPBACK WHALES
(Megaptera novaeangliae) Oceania population

EN | 12–15M | KRILL WITH SMALL AMOUNTS OF FISH AND PLANKTON

Humpback whales are a global conservation success story with most populations on the way to recovery from commercial whaling.

SEI WHALES
(Balaenoptera borealis)

EN | 15–16M | KRILL WITH SMALL FISH, SQUID AND COPEPODS

Half of the entire sei whale stock is thought to feed south of the Antarctic Convergence during the Austral summer.[15]

SOUTHERN RIGHT WHALES
(Eubalaena australis)

LC | 13.5–16M | KRILL AND COPEPODS (N OF 40 S)

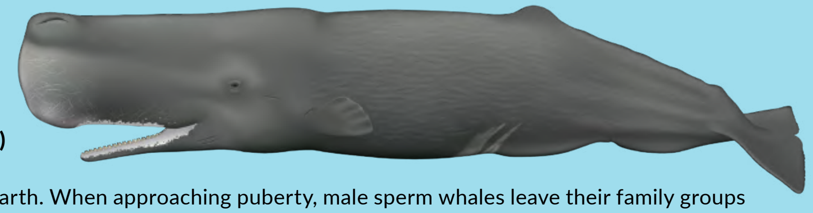
They have a circumpolar distribution in the southern hemisphere from approximately 20°S to 55°S, although they have been observed as far south as 65°S. They are migratory and few have been sighted in Antarctic waters in summer.

ANTARCTIC MINKE WHALES
(Balaenoptera bonaerensis)

NT | 9–11M | KRILL

Antarctic minke whales occur in greatest densities near the ice edge.[10]

TOOTHED WHALES
(Odontocetes)



SPERM WHALES
(Physeter microcephalus)

VU | 16–20M | SQUID (PRIMARY) WITH FISH

Sperm whales are the largest toothed predators on earth. When approaching puberty, male sperm whales leave their family groups and migrate toward polar seas. When reaching maturity, males return to the tropical and temperate seas to breed with females.[16]

KILLER WHALES
(Orcinus orca)

DD | 7-9.5M | SEALS, BALEEN WHALES AND PENGUINS

Three ecotypes (A,B,C) of killer whale are found in the Antarctic. Type A, Type B1 (pack-ice orcas) and Type B2 (Gerlache orcas) occur in the Peninsula region.

Type A

Large Type B1
Pack ice

Small Type B2
Gerlache

1. PROTECTING OCEAN GIANTS UNDER INCREASING PRESSURES

The Southern Ocean is critical habitat for most of the southern hemisphere's great whale populations.

Critical habitats for whales include areas used for feeding, breeding, raising offspring, socialising and migrating. They are areas "essential for day-to-day survival, as well as for maintaining a healthy population growth rate".[1]

Studying, monitoring and protecting whales in the Southern Ocean is crucial to secure healthy great whale populations in parts of the world as far away as Africa, the Pacific Islands, Oceania and South and Central America, where coastal communities increasingly depend on whale populations for burgeoning tourism and whale-watching industries.

During the 20th century, unchecked commercial whaling dramatically reduced whale populations throughout the Southern Ocean, driving many species to the brink of extinction. The international community has long since recognised the importance of protecting whales in the Southern Ocean, with the International Whaling Commission (IWC) specifically prohibiting commercial whaling through a moratorium on commercial whaling in 1982 and the establishment of the Southern Ocean Whale Sanctuary in 1994.

A growing body of evidence shows large whales play an important role in Southern Ocean ecosystem productivity. An orchestrated "whale pump", they are nature's engineers for an iron-poor ocean, facilitating the transfer of nutrients by releasing faecal plumes near the surface after feeding at depth and by moving nutrients from highly productive, high-latitude feeding areas to low-latitude calving areas.[2–4]

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Humpback whale head-breaching, Andvord Bay, Antarctica.

Our report focuses on the Antarctic Peninsula, a region rich in biodiversity including whales, ranging from year-round residents to species making long yearly migrations to this area to feed.

The Western Antarctic Peninsula is a hotspot of global environmental change. Climate change is having an increasing impact, warming the ocean and causing it to become more acidic.[5] Krill fishing is concentrated in this area and overlaps key feeding areas for large whales feeding on Antarctic krill (*Euphausia superba*). Tourism is intensifying, with large ships operating in areas that increase the risk of ship strikes and underwater noise pollution. Species that undertake long migrations from their breeding grounds in tropical waters navigate additional dangers through national waters including risks of bycatch in fishing gear and growing pollution.

With increasing risks comes opportunity to respond and there is much to be optimistic about. Since the commercial whaling moratorium by the IWC, most Southern Ocean humpback whale populations are recovering, becoming one of this century's greatest conservation success stories.[6] Innovation in whale research techniques has advanced our knowledge and insight into their long-lived nature and allows us to explore new areas of inquiry previously impossible to pursue.

Establishing broad, well-managed[7] marine protected areas (MPAs) is a vital part of delivering effective biodiversity conservation.

In protected areas of the ocean, activities are managed, limited or entirely prohibited. Antarctic ocean life is conserved through coordinated international management by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), which can make binding consensus decisions about controlling the use of marine living resources. It is now considering establishing an MPA in Antarctic Peninsula as part of a growing network of protected areas throughout the Southern Ocean.

However, under the Convention for the Conservation of Antarctic Marine Living Resources (the CAMLR Convention), whales are delegated to management under the IWC and are not considered in ecosystem-based management decisions related to commercial fishing and long-term monitoring under the CCAMLR Ecosystem Monitoring Program (CEMP).[8,9] We provide a case for greater knowledge exchange and formal collaboration with the IWC as extensive datasets are now available for CCAMLR to include in monitoring the fragile Antarctic ecosystem and for policymakers to protect these great ocean giants for generations to come.

2. WHALES OF THE ANTARCTIC PENINSULA

Antarctic minke whales, Wilhelmina Bay, Antarctica. One whale in this large group is carrying a green multi-sensor suction cup tag.

SPECIES FOUND IN THE ANTARCTIC PENINSULA ARE STILL RECOVERING FROM COMMERCIAL WHALING

During the 20th century, more than 2 million whales were commercially harvested to near extinction in the southern hemisphere,[17,18] including blue, fin, right, humpback, sei, minke and sperm whales taken from oceanic and coastal waters.

Throughout the Southern Ocean, more than 725,000 fin, 400,000 sperm, 360,000 blue, 200,000 sei and 200,000 humpback whales were killed during this time.[17]

Historically, the waters around the Antarctic Peninsula supported diverse and abundant baleen and toothed whale communities.

Antarctic blue whales are the world's largest living animal, with lengths up to 33.6m, and have a continuous circumpolar distribution around the continent.[19] In the summer, they feed almost exclusively on *euphausiids* (krill) - especially Antarctic krill[20]- predominantly near the edge of the pack-ice zone. Listed as critically endangered by the International Union for the Conservation of Nature (IUCN) Red List of Threatened Species, the population is less than 3% of its level of three generations ago (at least a 97% decline).[12] Antarctic blue whales are found in the region year-round, albeit with greatly reduced populations in winter months.[21]

An Antarctic blue whale estimated to be almost 30 metres in length.

Relatively high densities of fin whales – the second largest animal on the planet – are found in oceanic waters near the South Shetland Islands.[13,14] Likewise, the north-western portion of the Bransfield Strait and Scotia Sea contains increasing numbers of fin whales. Whereas more than 12,000 fin and 9,000 blue whales were killed in continental waters in the 1920s, relatively few fin and no blue whales are now found in these areas. With respect to blue whales, a small number of sightings are made annually from ships in the Drake Passage and concentrations of fin whales are often noted offshore of Boyd Strait.

Humpback whales are the most numerous and widespread baleen whale around the Antarctic Peninsula. Their summer distribution includes offshore waters but is concentrated on the continental shelf waters including the Bransfield and Gerlache Straits and coastal areas including Marguerite, Charlotte, Wilhelmina, Andvord, Dallman and Flandres Bays, and the Errera Channel. In summer, whales are distributed broadly, coincident with the distribution of krill, and by autumn, the whales are more aggregated in nearshore waters and bays adjacent to the Bransfield and Gerlache Straits. Both of these regions and their associated bays are critical habitat for humpback whales throughout the feeding season because of perpetually high krill density and the amount of ice-free water during summer and into late autumn.

Antarctic minke whales are also relatively common around the Antarctic Peninsula. Although highest densities are associated with the marginal/seasonal ice edge, minke whales inhabit the nearshore bays along the western side of the Antarctic Peninsula routinely. Their numbers are much lower in more open waters and exposed areas, in part due to predation risk from killer whales. North (in the Weddell Sea) and south of the Antarctic Peninsula, minke whale densities are likely to be higher in areas with more persistent and extensive sea-ice cover.

While there is little evidence of recovery in blue and fin whale populations, humpback and southern right whale numbers are increasing. Logistical difficulties limit our ability to reliably detect changes in minke whale numbers in the region but given the rapidly diminishing amount and duration of sea-ice cover here, their preferred habitat is decreasing precipitously.

Nearly all humpback whale populations in the southern hemisphere are recovering, some at rates near their biological maximum. While there is a great need to update the estimated abundance of humpback whales around the Antarctic Peninsula, there is little doubt that their numbers have been increasing quickly based on molecular genetic data and recent information on increased pregnancy rates of females.[22]

Three ecotypes of killer whale are found throughout the Antarctic. In the Antarctic Peninsula, Type A feed on minke whales and prefer open ocean areas. Type B1 (pack-ice orcas) are concentrated in nearshore sea-ice areas and feed on seals. Type B2 (Gerlache orcas) are smaller than Type A and have been known to feed on penguins.[23] Male sperm whales also frequent these waters.[24]

HUMPBACK WHALE MIGRATION

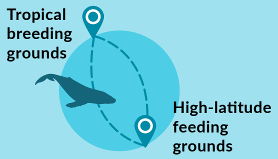
OCCURS OVER MULTIPLE INTERNATIONAL AND NATIONAL JURISDICTIONS IN THE SOUTH-EASTERN PACIFIC OCEAN

GLOBAL CONSERVATION SUCCESS - LOCAL TROUBLE AHEAD

EMERGING THREATS

Most Southern Ocean humpback whale populations are recovering and is one of this century's greatest conservation successes. However, research indicates emerging threats are on the horizon[6,27] for humpback whales migrating through the region.

HUMPBACK WHALES HAVE A STRUCTURED, ANNUAL MIGRATION CYCLE



Humpbacks migrate between **tropical breeding grounds** and **high-latitude feeding grounds** to feed on **Antarctic krill**, their primary prey.[25,26] In the south-eastern Pacific, this occurs over multiple international and national jurisdictions.

LONG, DANGEROUS JOURNEYS

8,461km

Undertakes one of the longest migrations of any mammal, with one-way distances of up to **8,461km** recorded.[33]

Return to the **same breeding and feeding grounds** year after year.[26]

FAT **5.5 to 7.5 MONTHS**

Subsist on stored fat reserves for **5.5 to 7.5 months** of every year.[26]

93% National waters

Travel almost entirely within national waters during their migratory journeys – **93% of transit time in national waters.**

BYCATCH & VESSEL STRIKES

Worldwide incidents of bycatch and vessel strikes are expected to **increase.**[30]

A Colombian study on humpback whale mortality found that **93%** were caused by **human factors:**

66% ENTANGLEMENT

20% VESSEL STRIKES

6.7% HUNTING

Gillnets and longlines represent serious threats to large cetaceans in Peru and the Southeast Pacific.[32]

CLIMATE CHANGE IMPACTS

Climate change effects are not uniform across regions and **may alter cues used by humpback whales to time and navigate their migration.**

KRILL SHIFT TO HIGHER LATITUDES

Warming ocean temperatures may cause **krill to shift to higher latitudes and decrease in abundance.**

INCREASE ENERGY NEEDS

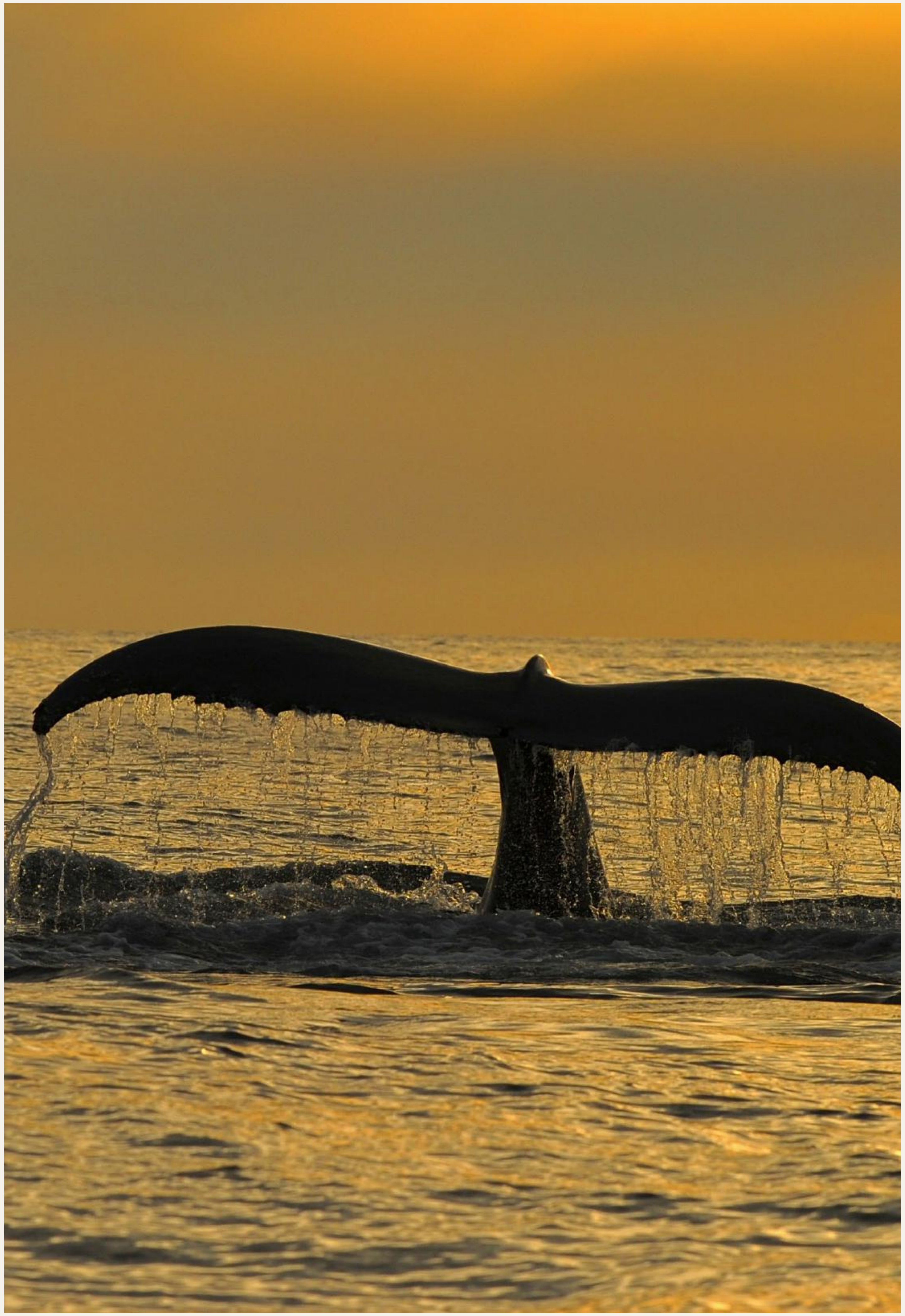
Longer migrations could increase the amount of energy whales need to obtain during feeding months to satisfy their enormous energetic demands.[25]

AFFECT ABILITY TO FIND MATES

Altered climate cues triggering migration could affect their **ability to find mates** and consequently **impact population growth.**[28,29]

ADVANCING SCIENCE - USING TECHNOLOGY TO TRACK MIGRATING WHALES

Between 2012 and 2018, scientists deployed 62 satellite tags on humpback whales providing fine-scale data from 70,291 transmissions over 2,899 days, 17 tags included migration data.



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Humpback whale on the move.

WHALES FACE SEVERAL RISKS IN THE REGION AND DURING MIGRATIONS

The ocean is warming along the Western Antarctic Peninsula. Since 1979, sea-ice duration has decreased by 85 days (+/-19).[34,35]

Since 1950, there has been a 6° Celsius increase in mean winter air temperature.[36] In addition, 596 of the 674 glaciers along the west coast of the peninsula have retreated due to ocean warming since records began in the 1940s.[37]

Baleen whales depend on krill for survival. Krill are small, semi-transparent crustaceans and a vital component of the Antarctic ecosystem. They are a main source of food for many mammals such as seals and whales, as well as birds and fish.[38] There are around 380 million tonnes of these shrimp-like crustaceans in the Southern Ocean,[39] similar to the total weight of human life on the planet.[40] They live for about seven years and are no larger than a little finger.

Past studies indicate that krill survival and lifecycle are directly linked to fluctuations in sea ice and have already revealed a decline in krill abundance.[41]

Long-distance migrants, such as humpback whales, occur disproportionately in higher latitudes where the speed and magnitude of climate change are the greatest, and are thought to be particularly vulnerable to the detrimental impacts through changes in habitat and prey availability and mismatches in timing.[25]

While humpback navigation remains a mystery, many marine mammals use ocean currents and fronts to navigate their routes. These same currents and fronts are projected to change with the warming climate.[25]

Reproduction and growth in living organisms are timed so that the most critical life stages coincide with periods of maximum resource availability. If the temperature and photoperiod cues used by whales and krill are different, rates of development between prey and predator may differ, leading to trophic cascades.[42]

Whales migrating through national waters are vulnerable to human interference. A study found that 93% of its recorded whale mortalities were from anthropogenic factors – of these, 66% from entanglement, 20% from vessel strikes and 6.7% from hunting. Calves were more affected than adults.[31]

BALEEN WHALES USE THE ANTARCTIC PENINSULA TO FEED ON KRILL – THE KEYSTONE SPECIES OF THE ANTARCTIC FOOD CHAIN

Across their range, fin, humpback and minke whales are known to be generalist feeders whose diet includes krill and schooling fish. However, around the Antarctic Peninsula – and Antarctica as a whole – their diet mostly comprises Antarctic krill. As well, blue whales are obligate krill feeders and their diet reflects this in the Antarctic. Southern right whales are known to feed on copepods and krill throughout their range but around the Antarctic they eat mainly krill. Because of the enormous biomass of krill relative to other potential prey items in the region, Antarctic krill are critical to baleen whale foraging success and population growth.

The amount of time humpback whales spend in Antarctic waters varies according to their sex, age and reproductive status:

- *pregnant females – approximately 6.5 months;*
- *mature males, juveniles, and resting females – approximately 5.5 months;*
- *females with calves – approximately 4.5 months.[26]*

Humpback distribution is best predicted by the distribution of Antarctic krill and proximity to the coast.[43–45] The seasonal movement patterns of the whales likely reflects that of krill: humpback whales are broadly distributed across the continental shelf in the summer and then move inshore to the straits and coastal bays in the autumn.[46,47]

In early summer, humpback whales spend their time feeding and transiting between feeding locations. By autumn, the whales spend more time feeding, less time transiting [48,49] and their home ranges become much smaller. This pattern likely reflects the seasonal movement of krill.[46,47]

Feeding behaviour is spatially and temporally clustered as krill are not uniformly distributed. The Gerlache and Bransfield Straits along with the adjacent bays (e.g. Wilhelmina, Andvord, Flandres) are the most important feeding areas for baleen whales around the Antarctic Peninsula.[48,50,51] These areas are used throughout the summer and become the exclusive feeding habitat in autumn as sea ice develops and krill move inshore in autumn.[46,47,52]

The highest densities of humpback whales reported are from aggregations in autumn in the nearshore bays around the Gerlache and Bransfield Straits.[50,51] In one day, more than 500 humpback whales and 2.3 million tonnes of krill were measured in Wilhelmina in May 2009.[50,53]

Humpback whales feed from the ocean's surface through to its lower depths. During summer months, whales generally feed in the upper 100 metres, and in autumn between the surface and as deep as 400 metres.[48,49,54–56]

With fewer ice-covered days and winter sea ice advancing later, humpback whales have available habitat for foraging later into the Antarctic autumn and winter. Tagging studies and surveys have shown high concentrations of whales in May and June and animals remaining around the peninsula into July.[46,56]

To survive their energetically costly migratory cycle, humpback whales may consume between 1 and 1.5 tonnes of krill a day during the foraging season.[57]

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Close up of a humpback whale feeding, showing its baleen plates and extended throat pleats. Baleen whales, like humpback whales, feed by gulping in water, and then pushing it out through the baleen plates with their tongue, Anvers Island.

KRILL FISHERIES OVERLAP IN KEY FEEDING HABITAT

Antarctic krill are harvested for use by aquaculture and poultry feed, as omega-3 health supplements for humans, in pet food and in medicine.[58]

CCAMLR management guidelines require that the krill fishery not interfere with population growth of Antarctic krill predators.[59] However, current management of the krill fishery has not considered or assessed the needs and behaviour of the largest krill predators in the Antarctic: baleen whales.[52]

In 2017, approximately 63% of the entire Antarctic krill fishery catch came from the Western Antarctic Peninsula and South Shetland Islands (CCAMLR Area 48.1). Of the 154,460 tonnes harvested from the Western Antarctic Peninsula in 2016, approximately 72% (106,983 tonnes) was harvested from the Antarctic Peninsula Bransfield Strait West and East small-scale management units.[60,61]

Current krill fishery catch in the Western Antarctic Peninsula coincides completely with the entire humpback whale foraging season. In the 2016 season, fisheries were active in the region between December 2015 and May 2016, in the 2017 season, between January and July.[60]

Fine-scale information on humpback presence suggests that the uniform krill catch limit for all small-scale management units in the Antarctic Peninsula is overly broad and ignores the fact that whale behaviour and krill catch effort are spatially clustered. Resolving the disparity between the spatial and temporal preference for specific areas by humpback whales and fishery vessels and the uniform nature of the krill catch limits is critical in minimising the potential conflict between whales and the fishery.[52]

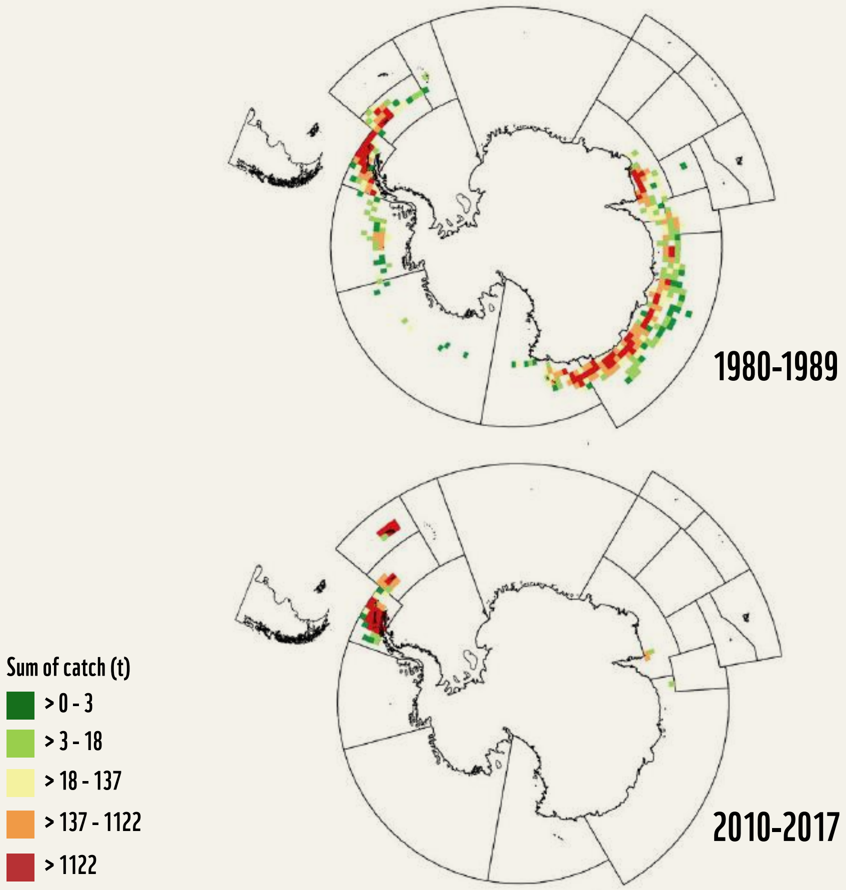
In 2003, CCAMLR agreed to define a suite of small-scale management units (SSMUs) for this region throughout the entire Area 48, based on the distribution of krill, krill predator foraging range and the fishery. However, there has been no agreement on the allocation of catch limits at this scale.[60] This is a critical next step in effectively managing the krill fishery and ensuring species that rely on krill remain safe.

The Antarctic krill fishery, with a total 2017 catch of 236,939 tonnes, currently operates without fine-scale information on whale movement, behavior and prey requirement.[60]

The *Antarctic Sea* fishing for krill along the Antarctic Peninsula.

Spatial and temporal overlap between whales and concentrated fishing activities could have negative implications for whales due to the potential for ship strikes and competition for krill.[52] As large predators, whales require high densities of krill to feed efficiently and satisfy their enormous energetic demands. Changes in both the overall abundance of krill locally as well as changes in patch structure from fishing could therefore have negative consequences for baleen whales.

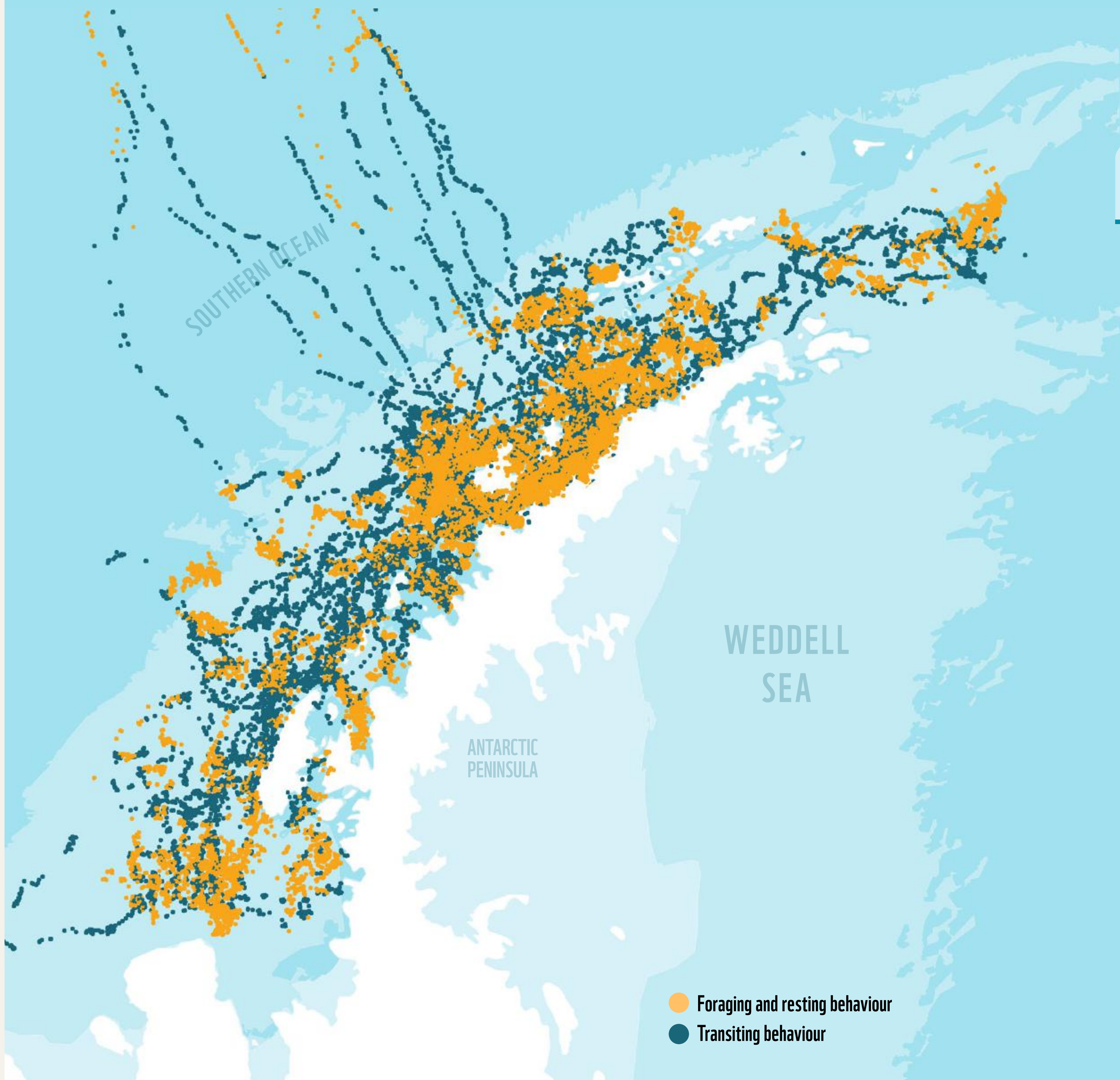
Figure 1: Krill fishing has focused on the Antarctic Peninsula and Scotia Arc in recent years, as shown by the spatial distribution of krill catch in the 1980s (top) and 2010 to 2017 (bottom).[60]



THE WESTERN ANTARCTIC PENINSULA IS CRITICAL FEEDING HABITAT FOR HUMPBACK WHALES

IMPORTANT FEEDING AREAS

The Gerlache and Bransfield Straits, together with adjacent bays – Wilhelmina, Andvord and Flandres – are the most important feeding areas[48,50,51] and become the exclusive feeding habitat in autumn as sea-ice develops.[46,47,52]



CLIMATE CHANGE IS IMPACTING HABITATS & PREY

SEA-ICE DURATION

85 DAYS

The ocean is warming. Since 1979, **sea-ice duration has decreased by 85 days annually (+/- 19).** [34,35]

Krill survival and lifecycle are directly linked to fluctuations in sea-ice and a decline in krill abundance has already been recorded.[41]

HUMAN ACTIVITIES ARE ON THE RISE

NOV TO JULY

Timing of the krill fishery activity in the peninsula coincides with the humpback whale foraging season - **November to July.**[26]

CONCENTRATED KRILL FISHING AND TOURISM ACTIVITIES

The **spatial and temporal overlap** between baleen whale feeding areas and concentrated **krill fishing and tourism activities** could have devastating impacts for whales due to

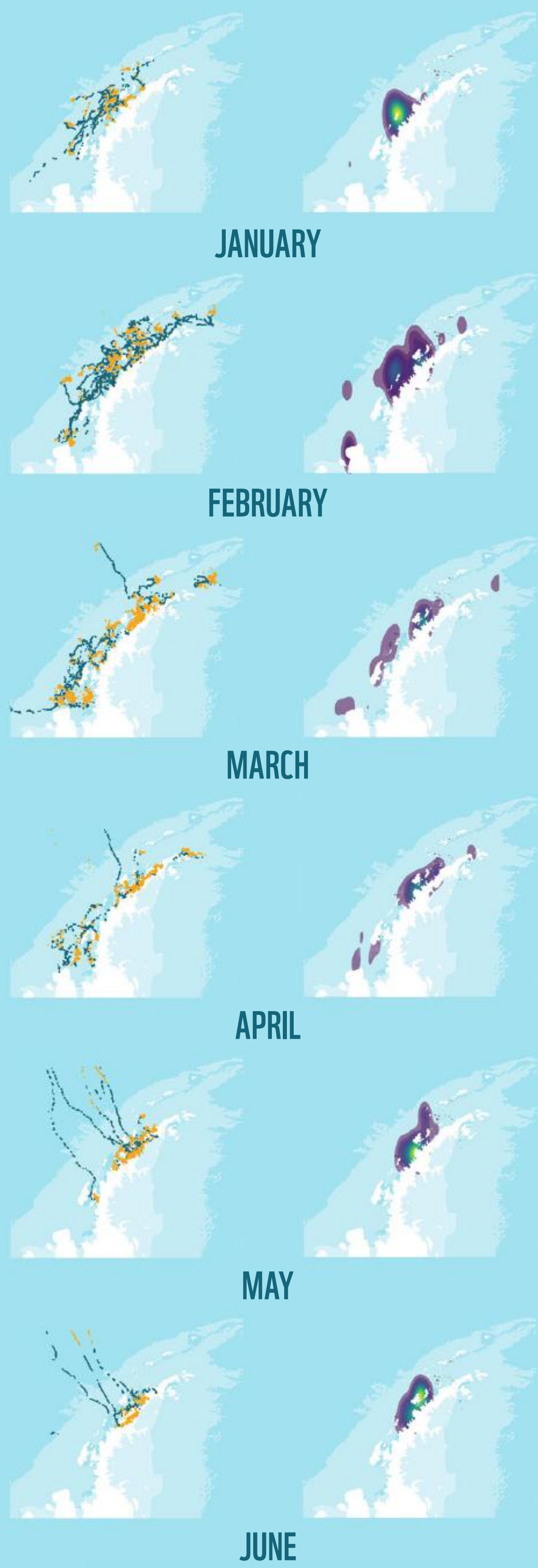
- **Intense competition for krill.**[52]
- **Increased risk of ship strikes.**[30]

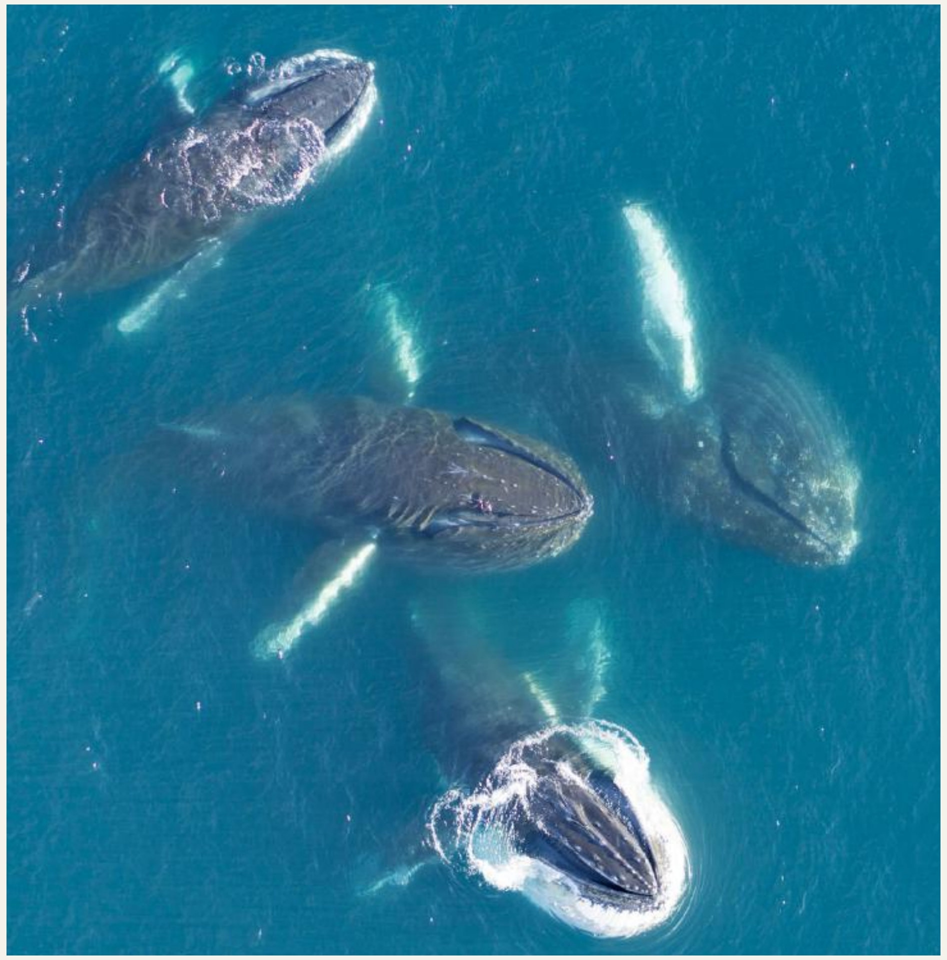
1 - 1.5 TONNES

Humpback whales may consume this amount of of krill per day during the foraging season.[57]

Satellite tag data of transiting and foraging/resting behaviour

Heatmaps of feeding behaviour





A pod of humpback whales feeding.

WHALES PLAY A CRITICAL ROLE IN SOUTHERN OCEAN ECOSYSTEMS

The Southern Ocean is the largest marine ecosystem in the world, with the polar front forming a distinct northern boundary to this ecoregion.[62]

There is increasing evidence whales and other top predators play a critical role in maintaining ocean health and global climate.[63]

Research suggests whales fertilise the ocean through their nutrient-rich faeces. These whale-krill relationships and the role of whales in maintaining ecosystem health will help inform the management of Antarctic krill fisheries and marine protected areas at CCAMLR.

The "whale pump" describes the phenomenon where whales and other large mammals release nutrients such as iron, carbon, nitrogen and sulphur from deep, nutrient-rich waters in shallower waters via feeding and excretion.[2,3,64–66]

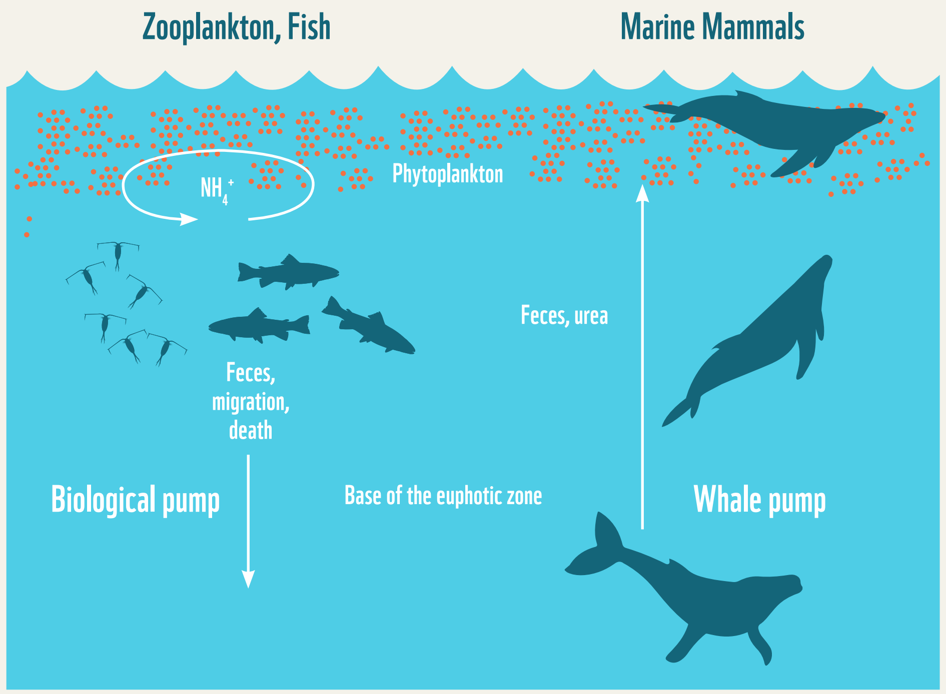
Marine mammals such as baleen whales primarily feed at depth during short dives followed by extended surface periods during which defecation can occur.[54,67]

Southern Ocean phytoplankton biomass and primary production are often limited by low iron (Fe) concentrations.[68] Research suggest that within these high-nutrient, low-chlorophyll waters, whales can supplement seawater iron concentrations via the consumption and excretion of krill biomass.[2,64–66] This can stimulate large phytoplankton blooms, increasing primary production, which is available for krill consumption.[2,4,69]

In 2018, at the International Whaling Commission meeting in Brazil, a resolution on ecosystem functioning recognising the key role whales play in the ocean ecosystem was passed by a majority vote. Once whales were simply viewed as resources, they are now seen as "ecosystem engineers", moving deep-sea nutrients into the sunlight where their faecal plumes fertilise the water and help the productivity of ecosystems.

The recovery of baleen whales, such as blue, humpback, fin and minke whales, may enhance nutrient availability for primary production to support prey populations. Conservation of whale habitat therefore benefits not only the whales, but the entire krill-based ecosystem, potentially increasing productivity in High Nutrient Low Chlorophyll areas of the Southern Ocean.[65] Protecting whales influences krill and all the species dependent on healthy krill populations.

Figure 2: An illustration of the "whale pump",[66] where whales release nutrients such as iron, carbon, nitrogen and sulphur from deep, nutrient-rich waters in shallower waters via feeding and excretion.



3. NEW SCIENCE IS CHANGING OUR UNDERSTANDING OF WHALES

TECHNOLOGY IS PROVIDING SCIENTISTS AND POLICYMAKERS WITH DATA TO BETTER UNDERSTAND, MONITOR AND CONSERVE ANTARCTIC WHALES

Historically, information on whales from the Antarctic was based largely on visual surveys that provided coarse estimates of distribution and abundance and correlations to environmental features.

Since the advent of biologging technology, the development of molecular techniques and other novel technologies, our ability to study the ecology, behaviour, physiology and conservation of whales around the Antarctic has significantly increased.

Satellite-linked tags provide information on distribution, movement patterns and behaviour over extended spatio-temporal scales and offer a means to better understand the seasonal habitat use and ecology of baleen whales in Antarctica.[47,52,70] These tags can provide information on the timing and routes of migration to and from Antarctic waters.

To date, significant advances in our understanding of where whales forage and how their behaviour changes throughout the feeding season has been made through tagging studies.[47,52,70] We better understand the critical foraging areas and times for humpback whales around the Antarctic Peninsula and can use this information to better inform fishing and management practices aimed at minimising competition for krill.

Concurrent to these studies, researchers have used short-term motion-sensing tags to quantify the underwater behaviour, feeding rates and energetics of Antarctic whales.[48,49,54,55,71] When these tags have been used together with quantitative measures of krill availability, researchers have been able to make great inferences into predator-prey relationships. This knowledge is critical to understand how whales maximise feeding and energetic demands while balancing their needs as an air-breathing mammal. For example, it has been shown that whales target denser prey and increase their foraging rates with increasing dive depth.[48] In this way, whales maximise energy gain per unit time. Tag data also provides information on buoyancy of whales and how this changes throughout the feeding season.[72] As whales increase their energy stores they become more buoyant, influencing the amount of energy required to dive to depth. Changes in foraging strategies late in the feeding season to target more shallow krill patches that migrate vertically at night is an example of how whales adapt their behaviour to maximise energetic gains while minimising costs.[48,49]

The use of unoccupied aircraft systems (UASs), or drones, to measure individual animals has helped scientists to determine animal health.[73,74] By measuring changes in the width of whales throughout the feeding season, we can estimate the rate of energy acquisition and determine the most critical periods for foraging. We can then combine this with tag data to determine not only the time of year that is most critical to whales, but also the critical areas and habitats for whales during these times of year. This is a fundamental step in our understanding of the ecology of whales in Antarctica and provides another opportunity to use information to better inform conservation and management plans to avoid the potential for competition between whales and commercial krill harvests.

Biopsy sampling extracts a small amount of blubber and tissue using a dart and is minimally invasive, providing critical information about whales.[22] Recent studies using new molecular genetic techniques have found that more than 95% of the humpback whales inhabiting the nearshore waters around the Antarctic Peninsula come from a single breeding population off the west coast of South and Central America.[75] Similarly, new methods to determine pregnancy from biopsy samples have revealed extremely high pregnancy rates in humpback whales, including a portion of the population that is breeding annually.[22] Furthermore, late in the feeding season, there is a disproportionately high number of pregnant females in the population, making it even more necessary to develop sound conservation and management strategies that allow for these whales (and other krill predators) to forage without competition.

As our knowledge of baleen whales grows, all species foraging throughout the peninsula will benefit from these techniques and technologies.

Based on several studies using a suite of novel approaches, we now have a greater understanding of the ecology and beahviour of humpback whales around the Antarctic Peninsula. These whales require vast quantities and high densities of krill to efficiently feed. The distribution of whales matches that of krill from being broadly distributed in early summer to more focused and concentrated around the Bransfield and Gerlache Straits and their associated bays in late summer and autumn. The diving and feeding behaviour of whales changes throughout the feeding season commensurate with changes in krill behaviour, allowing whales to maximise their energy intake and allowing for rapid population growth and reproduction. Pregnant females remain until late autumn, foraging extensively to satisfy their energetic needs and maintain a high population growth rate.

CASE STUDIES

Dr. Ari Friedlaender deploying a video-recording tag on an Antarctic minke whale, Penola Strait.

The video-recording and motion-sensing tag sits on the back of the Antarctic minke whale.

SATELLITE AND SUCTION-CUP TAGS UNCOVER WHALE FORAGING AREAS AND BEHAVIOUR

Researchers from the University of California Santa Cruz, Duke University and Stanford University are conducting several tagging studies to better understand the underwater behaviour of baleen whales and the ecological relationships between whales and their environment. To achieve this, they are deploying motion-sensing and video-recording tags on humpback and minke whales while concurrently using echosounders to measure prey availability. In this way, scientists can link feeding rates, movement patterns and behaviour of whales to aspects of whales' prey including patch size, density and depth.

Tags are being deployed using a hand-held carbon-fiber pole and placing the tag on the back of the whale. The tags attach via silicon suction cups and remain on the whale for 24 to 48 hours. During that time, tags measure depth, pitch, roll, direction, position, speed and temperature up to 400 times per second. After a set time, the tag automatically pops off and researcher retrieve it floating in the water using a radio tracker. A video camera in the tag records for up to 10 hours and allows researchers and the public to see the environment from the whale's perspective.

This is critical for a species like the minke whale that lives in sea ice. From the videos, scientists can determine how much time the whales spend in ice versus open waters, what kinds of sea-ice conditions they prefer and how they feed under sea ice. They can better understand how whales manoeuvre and attack prey patches by seeing the patch from the whale's perspective. And they can gain a better understanding of the social behaviour of the whales by seeing if whales are feeding in groups and how other animals are behaving relative to the tagged whale. This information is critical to scientists tasked with understanding the ecological role of baleen whales in Antarctic ecosystems, but it is also helpful to share it broadly to engage the public regarding the state of whales in the Antarctic.

LONG-TERM ECOLOGICAL RESEARCH – PALMER STATION, ANTARCTICA

For more than 30 years, the United States' National Science Foundation has supported an ecological research programme based at Palmer Station in the Antarctic Peninsula. The goals of this programme are to better understand the impacts of climate-driven changes on the structure and function of the Antarctic marine ecosystem. This programme has made significant advances including a greater understanding of how certain krill predators (e.g. Adelie penguins) are being impacted by climate change. Recently, a new component was added to the programme to better understand the ecological role of baleen whales in this ecosystem and how environmental change is affecting their recovery and interactions with other krill predators.

Using a suite of traditional and new technologies, researchers are now studying the population growth and foraging ecology of humpback whales. From skin and blubber samples, it has been shown that nearly all of the humpback whales inhabiting the inshore waters around the Antarctic Peninsula come from a single breeding population that winters off the coast of Central and South America.[75] This population is growing rapidly as evidenced by extremely high pregnancy rates among females, including a small percentage that are breeding annually (a rare occurrence for such large whales).[22]

From satellite-linked tags it has been shown that humpback whales are broadly distributed across the continental shelf area in early summer but move inshore following krill in autumn.[47,56] Throughout the summer months, the whales increase the amount of time they spend feeding so that the end of their foraging season is likely when they are gaining the most energy for upcoming migration to breeding grounds.[56] Whales are known to leave the Antarctic Peninsula between April and July depending on their life history and reproductive stage.

To understand the impacts of climate change on whales in Antarctica, a long-term program is needed that can track changes in individuals and populations over time scales that are relevant to the animals. The Palmer Station's research programme is unique in this way by allowing for an extended study on humpback whales.

Researchers fly a drone over a humpback whale in Wilhelmina Bay. The images will provide accurate estimates of body length and overall body condition.

DRONES UNCOVERING A NEW VIEW FROM ABOVE

Unoccupied aircraft systems (UASs), also known as drones, have developed rapidly as a result of recent advances in microelectronics and battery technology, and are revolutionising marine science and conservation. These new tools essentially provide on-demand remote-sensing capabilities at low cost and with reduced human risk.[76] A variety of multirotor, fixed-wing and transitional UAS platforms are capable of carrying various optical and physical sampling instruments and are being employed in almost every subdiscipline of marine science and conservation[76] including studies of killer,[77] humpback and minke whales along the Western Antarctic Peninsula.

UAS platforms and sensors are being applied in physical and biological science programs, and are increasingly being applied in natural resource management.[76] This includes studies ranging from assessing body condition, abundance, distribution and habitat use of cetaceans over large areas[78] to sampling respiratory microbiota from a whale's "blow".[79] Research on the potential effects of UASs on wildlife is growing; recent evidence on baleen whales demonstrates its effect is minimal even for animals close to the water surface.[80]

WWF has supported research into earlier development of low-cost drones to use photogrammetry studies on southern right whales to monitor their body condition (health) following long migrations.[73] WWF is collaborating with Duke University Marine Robotics and Remote Sensing Lab to apply drone technology to integrate remote sensing and machine learning in order to quantify changes in the body condition of populations of baleen whales. This technology will also be used to assess how penguins and seals are responding to a changing climate in the Western Antarctic Peninsula.

Dr David Johnston of Duke University holds a fixed-wing UAS.

STUDYING WHALES FROM SPACE

Antarctica can be a difficult place to conduct research given the logistical constraints of weather, cold, ship time and vastness of the area, so scientists are looking for alternative and remote ways to locate and count species, including whales. One new technology being considered is remote sensing or satellite imagery, which to date has been applied to land-based predators on the continent such as penguins[81,82] and seals.[83]

Several different satellites orbit the Antarctic region with varying degrees of resolution and frequency. Some researchers are now using these images to try and count whales from space. Machine-learning methods are being applied now that could train computer algorithms to search through huge amounts of data to locate the presence of whales in satellite images. To do this accurately, scientists in Antarctica are counting whales while satellites are taking pictures of a given area. These images are then manually processed to locate whales at the surface.

WWF is supporting the British Antarctic Survey to test the usefulness of satellite imagery to remotely count whales in the Western Antarctic Peninsula. The most recent study looked at comparing satellite counts with whale sightings from a boat-based survey by the Brazilian Antarctic Program. This summer-based study highlighted satellite imagery's ability to provide informative data on whale density and distribution, which may prove a useful alternative to traditional surveys in difficult to reach regions. The study now aims to use satellite imagery to monitor the presence of whales over the winter months where ice and weather restricts vessel movements.

An Antarctic minke whale surfaces in loose brash ice, Lemaire Channel, Antarctica.

TOURISM SHIPS AS PLATFORMS FOR RESEARCH, ENABLING CITIZEN SCIENCE

Access to the Antarctic is expensive. However, scientists are now collaborating with Antarctic tour operators to conduct research and share their experiences with passengers. For many years, penguin researchers have used tourist platforms to access colonies and make counts of nesting pairs. This information has been critical to assessing the impacts of changing climate on the numbers and species of penguins inhabiting the Antarctic Peninsula.[84]

Similarly, whale researchers are now using tourist ships as platforms for conducting research and sharing this information directly with passengers. One simple way for scientists to better understand whales is to count them and collect information on their distribution and abundance. To this end, passengers and naturalists are logging information whenever whales are encountered. Throughout the course of a given season or between seasons, scientists can use this information to better understand the distribution patterns of whales.

Tourist ships also offer scientists direct access to whales and the ability to deploy tags, collect biopsy samples or collect data on individual animals using drones – tools that are being used to better understand the behaviour of whales, their health and population growth, and how their body condition changes over time. WWF is funding tools such as digital tags to deploy on baleen whales and drones to monitor species and scale for use by trained researchers onboard.

All this information is critical to evaluate the impacts of human activities in the Antarctic and better understand these whales so that we can generate more appropriate and effective conservation strategies in a changing climate.

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Tourists photograph a humpback whale in Wilhelmina Bay.

WWF WILDCROWD – ENABLING ANTARCTIC CITIZEN SCIENTISTS TO MONITOR WHALES

WWF with Apple has developed Wildcrowd – a new open source mobile and web app for naturalists and field guides working in the polar tourism industry, and for citizen scientists visiting the Antarctic, to record sightings of marine species – including whales. Crowdsourcing the time, data, geolocation and image of wildlife encounters will help our conservation team and science collaborators identify, monitor and protect important ocean habitats in the Southern Ocean.

The Antarctic tourism sector is an untapped wealth of knowledge that can provide presence data of marine species including whales, penguins, seals and seabirds to better understand predator-prey relationships and distribution, and monitor critical feeding habitats in a changing climate.

Collaborating with researchers from Duke University's Marine Lab and University of California, Santa Cruz, we will train polar field guides how to use the platform on IAATO tourism vessels this upcoming Antarctic season. The team will produce species distribution models, enhance the functionality of the app over time and share learning.

Most citizen science projects work independently and many data sets contain a wealth of information that is unknown or unavailable to decision-makers.[85] Wildcrowd is an attempt to change this by facilitating these independent data and making them freely available in useable formats to government data portals, researchers and other projects. Website: **www.wildcrowd.net**

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WWF Antarctic Programme Lead, Chris Johnson tests the Wildcrowd app.

RESEARCHERS USE A RANGE OF TOOLS TO STUDY & MONITOR WHALES

SATELLITES

Satellites can be used to collect images to link with information on the presence of whales to determine features of the environment where whales occur. They can also be used to search for whales and count them in fine-scale images made from space.

Whale distribution, abundance

DRONES

Drones or Unoccupied Aircraft Systems are used to collect images of whales to determine body size and condition. These images can be used to determine during which parts of the season the whales are gaining the most energy.

Body condition (health), overall length

AERIAL SURVEYS

Using helicopters or planes, surveys conducted from the air can access areas difficult for ships to navigate in the ice. Following patterns, scientists can identify species location and later estimate abundance throughout the area.

Distribution, abundance, habitat

ACOUSTICS

Acoustic monitoring can tell researchers about the presence of whales that are vocalising, and when and where these occur. Acoustics can also be used to help understand whales' social behaviour and communication. Listening to the vocalisations of whales helps to identify their presence year-round.

Whale abundance, behaviour, density

TAGS

Short-term suction-cup tags are used to study the underwater behaviour and movement patterns of whales in Antarctica, providing information on feeding rates and dive patterns. Satellite tags provide information on seasonal movements, critical foraging areas and migration paths.

Movement, foraging behaviour, energy use, migratory behaviour

BIOPSY

Biopsy samples are used to better understand whales' population structure and life history. DNA analysis can determine the breeding population of a whale, if it is a male or female and – if female – if she is pregnant. Blubber analysis can help determine the diet of the whale and any contaminants that it has accumulated.

Population structure, pregnancy, diet, health

SHIP SURVEYS

Visual surveys for whales are routinely used to determine distribution and abundance patterns, which can then be linked to environmental features to determine critical habitat.

Distribution, abundance, habitat

PHOTO ID

This information allows researchers to track the movement of individual whales throughout and between seasons and helps determine links between feeding and breeding grounds.

Individual whale identity, population size, animal movement/ migration patterns

CITIZEN SCIENCE

Citizen science can be used to help collect high volumes of data on the location and number of whales present throughout the year and monitor impacts of environmental changes.

Timing and location of whale distribution and abundance

4. SCIENCE-BASED OPPORTUNITIES AND SOLUTIONS

Type B Antarctic killer whales cruising past a large ice berg, Antarctic Sound.

MARINE PROTECTED AREAS

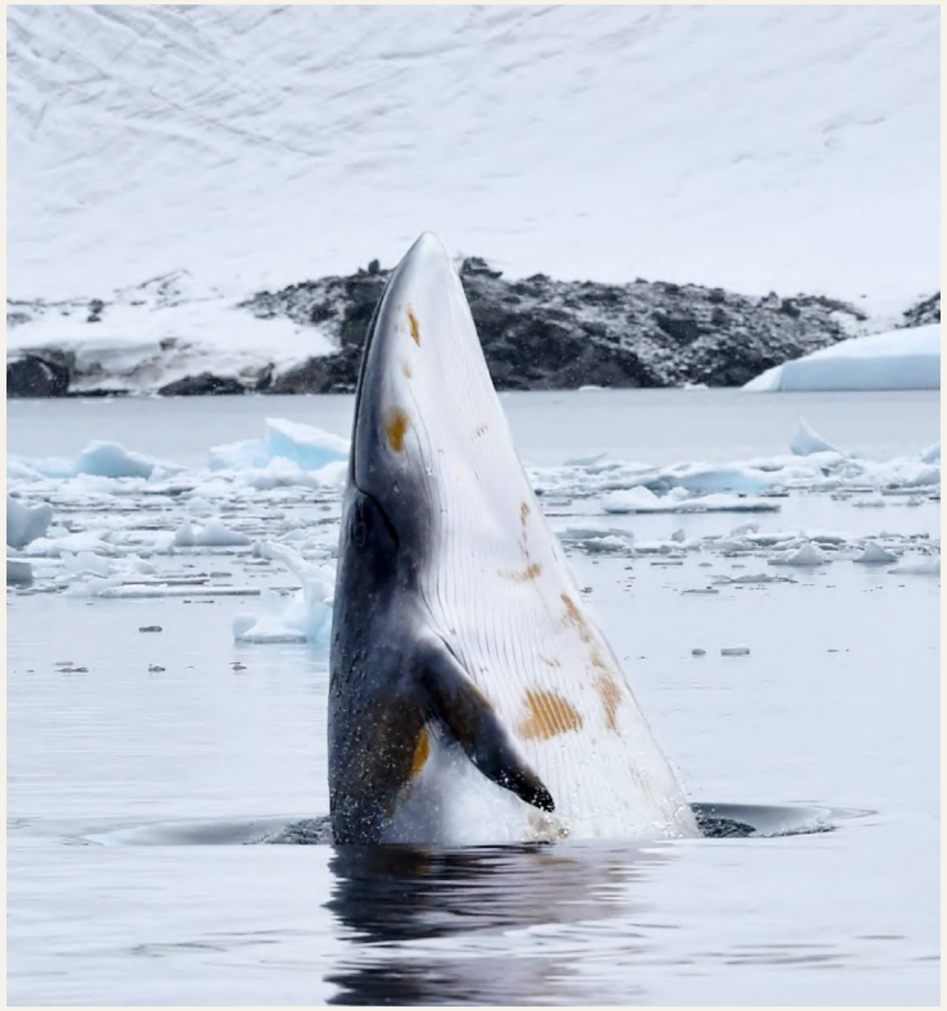
The Southern Ocean covers 10% of the world's oceans and includes some of the most productive marine areas in the world. There are more than 9,000 Antarctic marine species, with a great many species yet to be described.[86] Specialised benthic and pelagic habitats support a diverse range of species and foraging grounds for seabirds and mammals.[86] Many species are found only here, often limited to distinct areas, are slow growing, and have largely existed without impact from human activity until recently.[87] These species and habitats are particularly vulnerable to environmental changes.[88]

CCAMLR has committed to the creation of a representative system of marine protected areas (MPAs) throughout the Southern Ocean.[89] MPAs are designed to protect areas of ocean, coastal and seabed biodiversity by removing human pressures. Specific activities are managed, limited or banned in these areas to protect habitat or to achieve conservation objectives. MPAs protect regions from damage and exploitation, allowing species to multiply.[90]

Strategies are needed to adapt to a changing climate. Implementing effective marine protected areas will help conserve important Antarctic biodiversity including whales.[1] They can also be used as scientific reference zones to help monitor and understand the effects of fishing outside an MPA, as well as the impacts of climate change on Antarctic and Southern Ocean ecosystems.[91] Well-managed marine reserves will help marine ecosystems improve climate resilience.[91–93] By implementing management regimes such as marine protected areas (MPAs) targeting cetacean critical habitats, a range of species, ecosystems and ecosystem services may be secured.[1]

WWF urgently calls for CCAMLR to establish a comprehensive, effective network of marine protected areas surrounding the continent – including no-take marine sanctuaries – which are essential for safeguarding biodiversity and improving sustainable fisheries.

In July 2018, the Association of Responsible Krill Harvesting companies (ARK), comprising five fishing companies, voluntarily committed to restrict fishing around important breeding penguin colonies along the Antarctic Peninsula. Humanity's accelerating impact on fragile ocean ecosystems, including from climate change, makes this commitment to Antarctic protection all the more timely. WWF welcomes this commitment as a good step in the right direction. What is urgently needed now is a comprehensive and effective network of MPAs to be established in the region to protect the most important feedings areas for a range of krill predators including whales.



Antarctic minke whale breaching in brash ice, Paradise Harbor, Antarctica. The discolorations are diatoms, diagnostic of time in the ultra-productive waters around the Antarctic Peninsula.

OPPORTUNITIES FOR FUTURE RESEARCH AND MONITORING

More policy-focused research is needed to define, locate, understand and monitor the parameters of critical habitat for baleen whales and inform ecosystem-based management strategies that minimise the impact of overlap with commercial krill fisheries.

Whales are long-lived animals with some species still recovering from commercial whaling. Baleen whales are important krill predators and the Antarctic Peninsula is key feeding habitat. Investment in long-term monitoring is crucial, but it will take new collaborations between policy fora to truly action recommendations from science.

Article VI of the CAMLR Convention places responsibility for conservation and management of whales in the Southern Ocean with the IWC.[94] Both policy fora have dedicated scientific committees to inform management recommendations.

In particular, the IWC Southern Ocean Research Partnership (IWC-SORP) – established in 2009 – is an integrated, collaborative consortium for non-lethal whale research. It aims to maximise conservation-orientated outcomes for Southern Ocean cetaceans through an understanding of the post-exploitation status, health, dynamics and environmental linkages of their populations, and the threats they face.[95] The partnership provides knowledge back to the International Whaling Commission Science Committee (IWC-SC).

In 1989, CCAMLR established its ecosystem monitoring program (CEMP) to:

- detect and record significant changes in critical components of the marine ecosystem within the Convention Area, to serve as a basis for the conservation of Antarctic marine living resources;
- distinguish between changes due to harvesting of commercial species and changes due to environmental variability, both physical and biological.

While CEMP focuses on land predators, we have called for the programme to be modernised so that it includes whales and seals as part of its future monitoring efforts.[96]

This report outlines a suite of tools and technologies, ranging from digital tags to drones, that can be used by scientists in conjunction with partners, including the tourism industry, and citizen scientists to collect data on whale distribution and abundance. An added benefit is tourism guides can translate this information into educational messages for passengers, growing public support to protect Antarctic ocean giants.

While significant new information exists on humpback whale distribution for the areas around the Gerlache Strait and associated bays, the Bransfield Strait, waters around the South Shetland Islands and Antarctic Sound are poorly studied for all baleen whale species. Dedicated efforts to monitor whale movement and behaviour throughout the feeding season would significantly help to define critical habitats throughout the feeding season and understand the influence of climate change.

Similarly, we still lack fundamental data on the diving behaviour and feeding rates of all baleen whales. This information is critical for management and conservation strategies to limit the impact from overlap with krill fishing. We need to better understand at what depths whales feed and how they use different areas throughout the feeding season, including how this is affected by changes in krill distribution and abundance.

We highlight an urgent need for the scientific committees of the IWC and CCAMLR to formally collaborate, exchange knowledge and share data relevant to monitoring Antarctic whales under challenging environment changes into the 21st century.

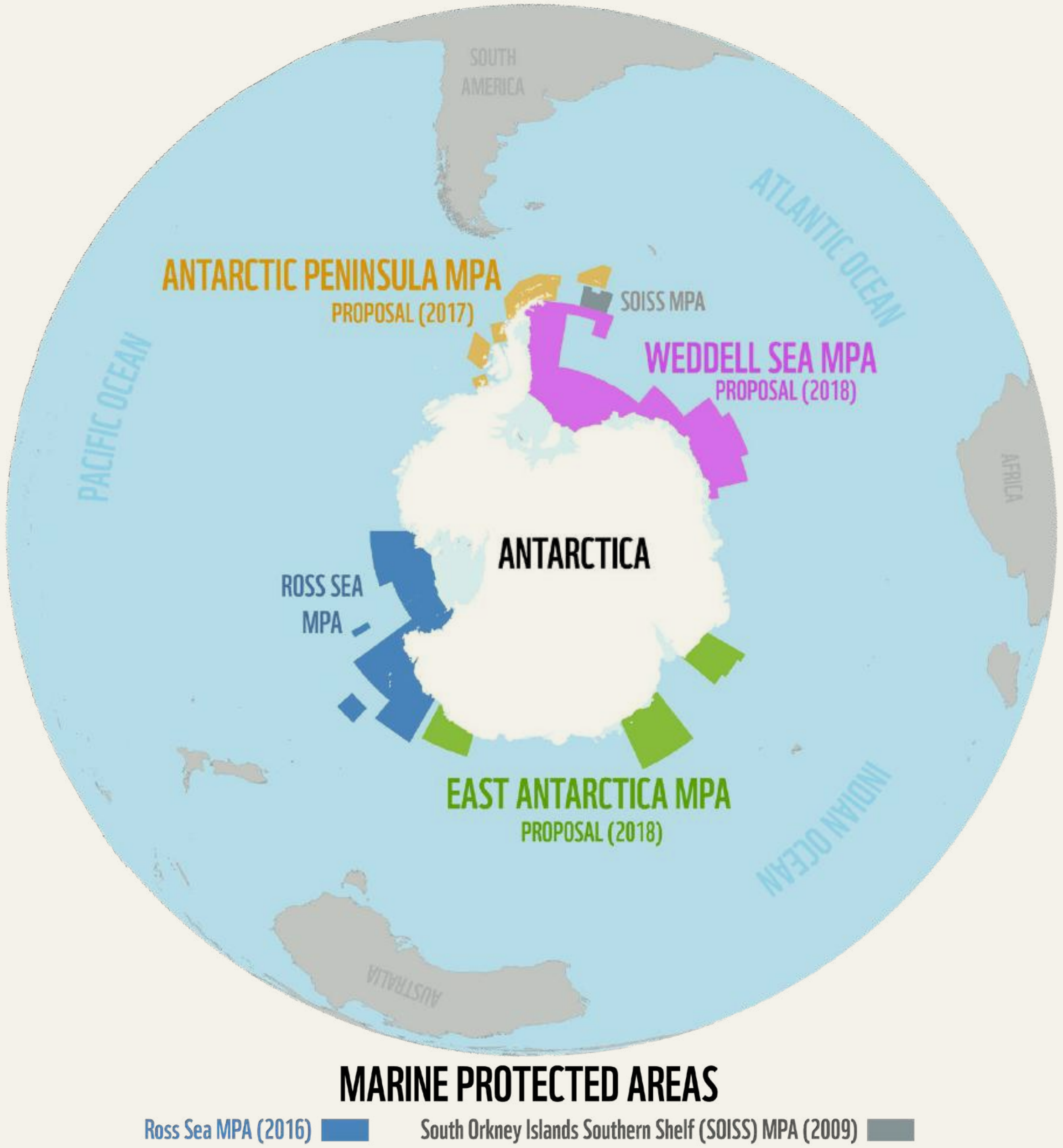


Figure 3: Current and proposed marine protected areas under consideration at CCAMLR in 2018.

5. REFERENCES

Killer whales hunting a leopard seal (*Hydrurga leptonyx*) on pack ice, Neumayer Channel, Antarctica.

1. Hoyt, E. *Marine Protected Areas* for Whales. (London: Earthscan, 2005).
2. Lavery, T. Whales sustain fisheries : Blue whales stimulate primary production in the Southern Ocean. (2014). doi:10.1111/mms.12108
3. Roman, J. et al. Whales as marine ecosystem engineers. *Front. Ecol. Environ.* **12**, 377–385 (2014).
4. Lavery, T. J. et al. Iron defecation by sperm whales stimulates carbon export in the Southern Ocean. *Proc. R. Soc. B Biol. Sci.* **277**, 3527–3531 (2010).
5. Turner, J. et al. Antarctic climate change and the environment: an update. *Polar Rec.* **50**, 237–259 (2014).
6. Bejder, M., Johnston, D. W., Smith, J., Friedlaender, A. & Bejder, L. Embracing conservation success of recovering humpback whale populations: Evaluating the case for downlisting their conservation status in Australia. *Mar. Policy* **66**, 137–141 (2016).
7. Edgar, G. J. et al. Global conservation outcomes depend on marine protected areas with five key features. *Nature* **506**, 216–20 (2014).
8. Agnew, D. J. Review—The CCAMLR Ecosystem Monitoring Programme. *Antarct. Sci.* (1997). doi:10.1017/S095410209700031X
9. CCAMLR. CCAMLR Ecosystem Monitoring Program (CEMP). Available at: https://www.ccamlr.org/en/science/ccamlr-ecosystem-monitoring-program-cemp. (Accessed: 19th September 2018)
10. IUCN. The IUCN Red List of Threatened Species. *Version 2018-1.* (2018). Available at: http://www.iucnredlist.org/.
11. Branch, T. A., Matsuoka, K. & Miyashita, T. Evidence for increases in Antarctic blue whales based on Bayesian modelling. Mar. Mammal Sci. (2004). doi:10.1111/j.1748-7692.2004.tb01190.x
12. Reilly, S. B. et al. Balaenoptera musculus ssp. intermedia (errata version published in 2016). *The IUCN Red List of Threatened Species 2008.* (2008). doi:10.2305/IUCN.UK.2008.RLTS.T41713A10543676.en
13. Santora, J. A., Schroeder, I. D. & Loeb, V. J. Spatial assessment of fin whale hotspots and their association with krill within an important Antarctic feeding and fishing ground. *Mar. Biol.* **161**, 2293–2305 (2014).
14. Herr, H. *et al.* Horizontal niche partitioning of humpback and fin whales around the West Antarctic Peninsula: evidence from a concurrent whale and krill survey. *Polar Biol.* **39**, 799–818 (2016).
15. Laws, R. M. Seals and Whales of the Southern Ocean. *Philos. Trans. R. Soc. B Biol. Sci.* (1977). doi:10.1098/rstb.1977.0073
16. Whitehead, H. & Weilgart, L. in *Cetacean societies: field studies of dolphins and whale* (eds. Mann, J., Connor, R. C., Tyack, P. L. & Whitehead, H.) 154–172 (The University of Chicago Press Chicago, 2000).
17. Rocha, R. C. et al. Emptying the Oceans: A Summary of Industrial Whaling Catches in the 20th Century. *Mar. Fish. Rev.* **76**, 37–48 (2015).
18. Tulloch, V. J. D., Plagányi, É. E., Matear, R., Brown, C. J. & Richardson, A. J. Ecosystem modelling to quantify the impact of historical whaling on Southern Hemisphere baleen whales. *Fish Fish.* **19**, 117–137 (2018).
19. Branch, T. A. et al. Past and present distribution, densities and movements of blue whales Balaenoptera musculus in the Southern Hemisphere and northern Indian Ocean. *Mamm. Rev.* 37, 116–175 (2007).
20. Mackintosh, N. A. & Wheeler, J. F. G. Southern blue and fin whales. *Discov. Reports* **1**, (1929).
21. Širovic, A. et al. Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula. *Deep. Res. Part II Top. Stud. Oceanogr.* (2004). doi:10.1016/j.dsr2.2004.08.005
22. Pallin, L. J. et al. High pregnancy rates in humpback whales (Megaptera novaeangliae) around the Western Antarctic Peninsula, evidence of a rapidly growing population. R. *Soc. Open Sci.* **5**, (2018).
23. Pitman, R. & Ensor, P. Three forms of killer whales (Orcinus orca) in Antarctic waters. *J. Cetacean Res. Manag.* (2003). doi:10.1038/news050606-2
24. Thiele, D. et al. Seasonal variability in whale encounters in the Western Antarctic Peninsula. *Deep. Res. Part II Top. Stud. Oceanogr.* **51**, 2311–2325 (2004).
25. Learmonth, J. A. et al. Potential Effects of Climate Change on Marine Mammals. *An Annu. Rev.* **44**, 431–464 (2006).
26. Norris, K. & Dawbin, W. *Whales, dolphins, and porpoises.* (Univ. of California Press, 1966).
27. NOAA. Successful conservation efforts pay off for humpback whales | National Oceanic and Atmospheric Administration. (2016).
28. Visser, M. E., Both, C. & Lambrechts, M. M. Global Climate Change Leads to Mistimed Avian Reproduction. *Adv. Ecol. Res.* **35**, 89–110 (2004).
29. Robinson, R. et al. Travelling through a warming world: climate change and migratory species. *Endanger. Species Res.* **7**, 87–99 (2009).
30. Elizabeth Alter, S., Simmonds, M. P. & Brandon, J. R. Forecasting the consequences of climate-driven shifts in human behavior on cetaceans. *Mar. Policy* **34**, 943–954 (2010).
31. Capella, J., Florez-Gonzalez, L. & Falk Fernandez, P. *Mortality and anthropogenic harassment of humpback whales along the pacific coast of Colombia Cetaceans of Colombia View project Ecology and conservation of humpback whales in Southeast Pacific.* (2001).
32. García-Godos, I., Waerebeek, K. Van, Alfaro-Shigueto, J. & Mangel, J. C. Entanglements of Large Cetaceans in Peru: Few Records but High Risk. *Pacific Sci.* (2013). doi:10.2984/67.4.3
33. Rasmussen, K. *et al.* Southern Hemisphere humpback whales wintering off Central America: insights from water temperature into the longest mammalian migration. *Biol. Lett.* **3**, 302–5 (2007).
34. Stammerjohn, S. E., Martinson, D. G., Smith, R. C., Yuan, X. & Rind, D. Trends in Antarctic annual sea ice retreat and advance and their relation to El Niño–Southern Oscillation and Southern Annular Mode variability. *J. Geophys. Res.* **113**, C03S90 (2008).
35. Stammerjohn, S., Massom, R., Rind, D. & Martinson, D. Regions of rapid sea ice change: An inter-hemispheric seasonal comparison. *Geophys. Res. Lett.* **39**, n/a-n/a (2012).
36. Vaughan, D. G. et al. Recent Rapid Regional Climate Warming on the Antarctic Peninsula. *Clim. Change* **60**, 243–274 (2003).
37. Cook, A. J. et al. Ocean forcing of glacier retreat in the western Antarctic Peninsula. *Science* (80-.). **353**, 283–286 (2016).
38. Hill, S. L., Cavanagh, R. D., Knowland, C. A., Grant, S. & Downie, R. *Bridging the Krill Divide: Understanding Cross-Sector Objectives for Krill Fishing and Conservation.* (British Antarctic Survey, 2014).
39. Atkinson, A., Siegel, V., Pakhomov, E. A., Jessopp, M. J. & Loeb, V. A re-appraisal of the total biomass and annual production of Antarctic krill. *Deep Sea Res. Part I* **56**, 727–740 (2009).
40. Walpole, S. C. *et al.* The weight of nations: an estimation of adult human biomass. *BMC Public Health* **12**, 439 (2012).
41. Atkinson, A., Siegel, V., Pakhomov, E. & Rothery, P. Long-term decline in krill stock and increase in salps within the Southern Ocean. *Nature* **432**, 100–103 (2004).
42. Visser, M. E. & Both, C. Shifts in phenology due to global climate change: the need for a yardstick. *Proceedings. Biol. Sci.* **272**, 2561–9 (2005).
43. Friedlaender, A. et al. Whale distribution in relation to prey abundance and oceanographic processes in shelf waters of the Western Antarctic Peninsula. *Mar. Ecol. Prog. Ser.* **317**, 297–310 (2006).
44. Robbins, J. *et al.* Return movement of a humpback whale between the Antarctic Peninsula and American Samoa: a seasonal migration record. *Endanger. Species Res.* **13**, 117–121 (2011).
45. Friedlaender, A. S., Fraser, W. R., Patterson, D., Qian, S. S. & Halpin, P. N. The effects of prey demography on humpback whale (Megaptera novaeangliae) abundance around Anvers Island, Antarctica. *Polar Biol.* **31**, 1217–1224 (2008).
46. Weinstein, B. G. & Friedlaender, A. S. Dynamic foraging of a top predator in a seasonal polar marine environment. *Oecologia* **185**, 427–435 (2017).
47. Curtice, C. *et al.* Modeling the spatial and temporal dynamics of foraging movements of humpback whales (Megaptera novaeangliae) in the Western Antarctic Peninsula. *Mov. Ecol.* **3**, 13 (2015).
48. Friedlaender, A. S. *et al.* Multiple-stage decisions in a marine central-place forager. *R. Soc. Open Sci.* **3**, 160043 (2016).
49. Friedlaender, A., Tyson, R., Stimpert, A., Read, A. & Nowacek, D. Extreme diel variation in the feeding behavior of humpback whales along the western Antarctic Peninsula during autumn. *Mar. Ecol. Prog. Ser.* **494**, 281–289 (2013).

50. Nowacek, D. P. *et al.* Super-Aggregations of Krill and Humpback Whales in Wilhelmina Bay, Antarctic Peninsula. *PLoS One* **6**, e19173 (2011).

51. Johnston, D., Friedlaender, A., Read, A. & Nowacek, D. Initial density estimates of humpback whales Megaptera novaeangliae in the inshore waters of the western Antarctic Peninsula during the late autumn. *Endanger. Species Res.* **18**, 63–71 (2012).

52. Weinstein, B. G., Double, M., Gales, N., Johnston, D. W. & Friedlaender, A. S. Identifying overlap between humpback whale foraging grounds and the Antarctic krill fi shery. *Biol. Conserv.* **210**, 184–191 (2017).

53. Espinasse, B. *et al.* Austral fall-winter transition of mesozooplankton assemblages and krill aggregations in an embayment west of the Antarctic Peninsula. *Mar. Ecol. Prog. Ser.* **452**, 63–80 (2012).

54. Ware, C., Friedlaender, A. S. & Nowacek, D. P. Shallow and deep lunge feeding of humpback whales in fjords of the West Antarctic Peninsula. *Mar. Mammal Sci.* **27**, 587–605 (2011).

55. Tyson, R. B., Friedlaender, A. S. & Nowacek, D. P. Does optimal foraging theory predict the foraging performance of a large air-breathing marine predator? *Anim. Behav.* **116**, 223–235 (2016).

56. Weinstein, B., Irvine, L. & Friedlaender, A. S. Capturing foraging and resting behavior using nested multivariate Markov models in an air-breathing marine vertebrate. *Mov. Ecol.* (2018).

57. Chittleborough, R. Dynamics of two populations of the humpback whale, Megaptera novaeangliae (Borowski). *Mar. Freshw. Res.* **16**, 33 (1965).

58. Brunner, E. J., Jones, P. J. S., Friel, S. & Bartley, M. Fish, human health and marine ecosystem health: policies in collision. *Int. J. Epidemiol.* **38**, 93–100 (2009).

59. Kawaguchi, S., Nicol, S., Taki, K. & Naganobu, M. *Fishing ground selection in the Antarctic krill Fishery: trends in patterns Across years, seasons And nations. CCAMLR Science* **13**, (2006).

60. CCAMLR. *Krill Fishery Report 2017. Commission for the Conservation of Antarctic Marine Living Resources* (2017). doi:https://www.ccamlr.org/en/system/files/00%20KRI48%202015_1.pdf

61. CCAMLR. CCAMLR Statistical Bulletin Vol. 30. (2018).

62. Knox, G. A. Biology of the Southern Ocean. *CRC Press* (2006). doi:10.1201/9781420005134.fmatt

63. Savoca, M. S. & Nevitt, G. A. Evidence that dimethyl sulfide facilitates a tritrophic mutualism between marine primary producers and top predators. *Proc. Natl. Acad. Sci.* **111**, 4157–4161 (2014).

64. Ratnarajah, L. *et al.* A preliminary model of iron fertilisation by baleen whales and Antarctic krill in the Southern Ocean: Sensitivity of primary productivity estimates to parameter uncertainty. *Ecol. Modell.* **320**, 203–212 (2016).

65. Ratnarajah, L., Bowie, A. R., Lannuzel, D., Meiners, K. M. & Nicol, S. The biogeochemical role of baleen whales and krill in Southern Ocean nutrient cycling. *PLoS One* **9**, 1–18 (2014).

66. Nicol, S. *et al.* Southern Ocean iron fertilization by baleen whales and Antarctic krill. *Fish Fish.* **11**, 203–209 (2010).

67. Roman, J. & McCarthy, J. J. The whale pump: Marine mammals enhance primary productivity in a coastal basin. *PLoS One* **5**, (2010).

68. Pollard, R. T. *et al.* Southern Ocean deep-water carbon export enhanced by natural iron fertilization. *Nature* **457**, 577–580 (2009).

69. Blain, S. *et al.* Effect of natural iron fertilization on carbon sequestration in the Southern Ocean. *Nature* (2007). doi:10.1038/nature05700

70. Riekkola, L. *et al.* Application of a multi-disciplinary approach to reveal population structure and Southern Ocean feeding grounds of humpback whales. *Ecol. Indic.* **89**, 455–465 (2018).

71. Friedlaender, A. S. *et al.* Feeding rates and under-ice foraging strategies of the smallest lunge filter feeder, the Antarctic minke whale (Balaenoptera bonaerensis). *J. Exp. Biol.* **217**, 2851–2854 (2014).

72. Narazaki, T. *et al.* Body density of humpback whales (megaptera novaengliae) in feeding aggregations estimated from hydrodynamic gliding performance. *PLoS One* **13**, 1–23 (2018).

73. Christiansen, F. *et al.* Maternal body size and condition determine calf growth rates in southern right whales . *Mar. Ecol. Prog. Ser.* **592**, 267–281 (2018).

74. Christiansen, F., Dujon, A. M., Sprogis, K. R., Arnould, J. P. Y. & Bejder, L. Non-invasive unmanned aerial vehicle provides estimates of the energetic cost of reproduction in humpback whales Appendix S2 : Supplementary analyses. *Ecosphere* **7**, 1–7 (2016).

75. Albertson, R. *et al.* Genetic identification , temporal and mixed- stock analyses of humpback whales (Megaptera novaeangliae) in the nearshore waters of western Antarctic Peninsula. in *Meeting of the IWC Scientific Committee* (2015).

76. Johnston, D. W. Unoccupied Aircraft Systems in Marine Science and Conservation. *Ann. Rev. Mar. Sci.* (2018). doi:10.1146/annurev-marine-010318-095323

77. Durban, J. W., Fearnbach, H., Perryman, W. L. & Leroi, D. J. Photogrammetry of killer whales using a small hexacopter launched at sea. *J. Unmanned Veh. Syst.* **3**, 1–5 (2015).

78. Hodgson, A., Peel, D. & Kelly, N. Unmanned aerial vehicles for surveying marine fauna: Assessing detection probability. *Ecol. Appl.* **27**, 1253–1267 (2017).

79. Geoghegan, J. L. et al. Virological sampling of inaccessible wildlife with drones. *Viruses* **10**, 1–7 (2018).

80. Christiansen, F., Rojano-Doñate, L., Madsen, P. T. & Bejder, L. Noise Levels of Multi-Rotor Unmanned Aerial Vehicles with Implications for Potential Underwater Impacts on Marine Mammals. *Front. Mar. Sci.* **3**, 1–9 (2016).

81. Fretwell, P. T. *et al.* An emperor penguin population estimate: The first global, synoptic survey of a species from space. *PLoS One* **7**, (2012).

82. LaRue, M. A. *et al.* A method for estimating colony sizes of Adélie penguins using remote sensing imagery. *Polar Biol.* **37**, 507–517 (2014).

83. LaRue, M. A. *et al.* Satellite imagery can be used to detect variation in abundance of Weddell seals (Leptonychotes weddellii) in Erebus Bay, Antarctica. *Polar Biol.* **34**, 1727–1737 (2011).

84. Lynch, H. J., Naveen, R., Trathan, P. N. & Fagan, W. F. Spatially integrated assessment reveals widespread changes in penguin populations on the Antarctic Peninsula. *Ecology* (2012). doi:10.1890/11-1588.1

85. Bonney, R. et al. Citizen science: Next steps for citizen science. *Science* (80-.). **343**, 1436–1437 (2014).

86. Griffiths, H. J. Antarctic marine biodiversity - what do we know about the distribution of life in the southern ocean? *PLoS One* **5**, e11683 (2010).

87. Verde, C. & di Prisco, G. *Adaptation and Evolution in Marine Environments, Volume 2: The Impacts of Global Change on Biodiversity.* (Springer Berlin Heidelberg, 2014).

88. Goldsworthy, L., Zuur, B. & Llewellyn, G. in *Big, Bold and Blue: Lessons from Australia's Marine Protected Areas.* (eds. Fitzsimons, J. & Wescott, G.) (CSIRO Publishing, 2016).

89. Brooks, C. M. Competing values on the Antarctic high seas: CCAMLR and the challenge of marine-protected areas. *Polar J.* **3**, 277–300 (2013).

90. Edgar, G. J. *et al.* Global conservation outcomes depend on marine protected areas with five key features. *Nature* **5**, 216–20 (2014).

91. Hopkins, C. R., Bailey, D. M. & Potts, T. Perceptions of practitioners: Managing marine protected areas for climate change resilience. *Ocean Coast. Manag.* **128**, 18–28 (2016).

92. Roberts, C. M. et al. Marine reserves can mitigate and promote adaptation to climate change. *Proc. Natl. Acad. Sci.* **114**, 6167–6175 (2017).

93. Olds, A. D. *et al.* Marine reserves help coastal ecosystems cope with extreme weather. *Glob. Chang. Biol.* **20**, 3050–3058 (2014).

94. CCAMLR. CAMLR Convention Text. Available at: https://www.ccamlr.org/en/organisation/camlr-convention-text. (Accessed: 20th September 2018)

95. IWC. Southern Ocean Research Partnership. (2018). Available at: http://www.marinemammals.gov.au/sorp. (Accessed: 18th September 2018)

96. Johnson, C. *et al. WWF Tracking Antarctica - An update on the state of Antarctica and the Southern Ocean.* (2016). doi:10.13140/RG.2.2.31957.01767

NEW TECHNOLOGIES

Scientists have a range of tools to better study and monitor whale populations, distribution and movement.

ANTARCTIC PENINSULA

This region is a critical feeding habitat for humpback, minke and fin whales targeting Antarctic krill.

KRILL FISHING

Krill fishing overlaps with key feeding areas for whales in this region.

MARINE PROTECTED AREAS

MPAs will help the recovery and conservation of whales.

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