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Supplementary Table 3.

Key physical drivers, their properties, ecological importance and sources of information, with a focus on the Southern Ocean pelagic food web

The first part and main focus of this table (Part I) is sea ice. The second part of the table (Part II) briefly summaries information for some of the other key drivers, detailing aspects that are particularly important ecologically, providing a baseline for future iterative work.

Part I

Parameter	**Ecological importance**
Sea ice[1-21] Influences physical conditions, e.g. release of freshwater, ocean stratification, air-sea interactions, light availability, vertical mixing and temperature.	*Biogeochemical:* Influences biogeochemical cycles, e.g. in regulating the "biological pump," uptake and sequestration of atmospheric CO_2, ocean upwelling and outgassing, ocean acidification, and effects on nutrient dynamics and availability; *Phytoplankton*: The effects on the physical conditions together with the above biogeochemical processes influence the extent, timing and composition of phytoplankton blooms. E.g. mixing of the upper water column through a combination of ice melting and winds, increased light availability and temperature can result in intense primary production. The marginal ice zone is particularly productive in the spring and summer months owing to a combination of these factors. *Zooplankton*: The above factors influence food type and availability for herbivorous grazers, thus in turn also affect the distribution and abundance of predatory zooplankton. Related consequences include

	effects on development, e.g. the timing of diapause for copepods. *Fish and air-breathing predators:* Fish, penguins, seals and whales are also influenced by the above effects on the timing and availability of food at the different trophic levels.
Provides crucial habitat for many species.	*Phytoplankton*: Provides a substrate for sea ice algae which is a crucial food source for grazers such as Antarctic krill when food resources are low in winter; *Zooplankton:* Provides refuge for species such as krill; important over-wintering habitat for some species; *Fish and air-breathing predators:* Provides refuge for species e.g. silverfish; also important to several species for spawning and as an early nursery; important over-wintering habitat for some species. Important for air-breathing predators for haul out; access to food; access to air to breath; and breeding location. Some species e.g. Adélie penguins and crabeater and Weddell seals are sea ice obligate, some species e.g. gentoo penguins are 'ice intolerant'. For pack-ice seals, sea ice provides vital breeding and resting habitat, affords protection from predators, and affects the distance they need to travel to areas that concentrate Antarctic krill, their main prey.
Acts as a physical barrier: allows or restricts movement/access of species and fishing vessels.	Sea ice can directly affect the distribution of species at different trophic levels. E.g. it can have a detrimental effect restricting access between feeding sites and land-based breeding colonies;

	Fisheries: Influence on Southern Ocean fisheries e.g. effects on target species, access of vessels to fishing grounds.
Properties of ecological importance include:	
Extent describes areal coverage. Sea ice extent around the Antarctic ranges from ~19 million km^2 each winter to ~3-4 million km^2 each summer. Seasonality describes the timing of annual sea ice expansion and contraction (and resultant ice season duration).	The extent and timing of sea ice is closely linked with ecological processes. The 'ice season duration' is ecologically important for any given location. Increased primary production occurs at sea ice edges during the spring and summer sea ice retreat, and many species are closely linked to the timing and characteristics of the spring bloom. Variability in timing, duration and extent impacts food availability during critical periods of species' life cycles. The life cycles of many species are closely linked to sea ice seasonality, e.g. the timing of spring sea ice retreat and associated blooms are critical for adult female krill to reach optimal breeding conditions. Higher up the food web, another example is shown by the timing of sea ice break-out being closely linked with the influx of non-breeding Antarctic fur seals at Signy Island, South Orkneys.
Concentration provides information on how much ice there is at a given location relative to the total.	Extreme ice concentration can hinder the ability of higher predators to locate and access their prey, traverse the sea ice zone, access air to breathe and haul-out.
Thickness	Thickness particularly influences light levels and water temperature under the ice as well as suitability as a physical habitat. Vertical distribution of ice algae is dependent on thickness, which in turn may impact the availability of food for pelagic grazers. Thicker rafted ice provides a better refuge for juvenile krill than thinner under-formed ice. Ice thickness may also affect seal pupping success for some species.

Permeability	Ice permeability affects nutrient availability, which in turn affects net productivity, prey assemblages and predator populations.
Type of ice, e.g. stationary fast ice or moving pack ice have different properties.	The properties of the different types of ice influence ecology in different ways. E.g. fast ice is important as a habitat for microorganisms and sea ice algae, and as a breeding platform for Weddell seals and emperor penguins. Strong links have been found between Adélie penguin reproductive success and ice type.
Snow cover	Snow cover affects light penetration, ice algal dynamics, nutrient transport, surface communities, breeding site availability and egg/offspring survival, and duration of the ice presence. E.g. increased snow precipitation accumulating at breeding sites has been shown to affect the survival of Adélie penguin chicks.
Polynyas	Significant ecological importance e.g. they can be "hotspots" for primary production, influence the extent of fast ice, and timing/seasonal meltback of pack ice.

Part II

Parameter	**Ecological importance**
Temperature (ocean and air) [1,7,14,22-27]	
Atmospheric temperatures affect heat input to surface waters of the ocean and also influence meltwater from coastal sources.	Species vary in their thermal tolerance and temperature has a major role in polar ecological processes, spanning a broad range of influence including primary productivity, growth, metabolism,

Properties of ecological importance include: Maximum and minimum temperatures (air and water), but also finer-scale spatial and temporal temperatures.	thermoregulation, life cycles, reproductive success, species assemblages, distribution and range. The effects of temperature on physical aspects such as meltwater may influence primary production.
Winds[10,14,28-31] The Southern Ocean is directly influenced by strong westerly winds that exist over the Antarctic Circumpolar Current (ACC) and by easterly winds closer to the continent. *Properties of ecological importance include:* <u>Velocities, strength and position:</u> influence circulation, sea ice, stratification, mixed layer depths (MLD), vertical Ekman pumping and sea surface temperature, nutrient transport, oceanic carbon and oxygen uptake and storage.	Wind properties influence primary production, for example, major changes in phytoplankton biomass and community composition have been reported due to changes in winds affecting conditions such as MLD. Wind speed is an important driver of ice edge algal blooms. Winds directly influence movement and distribution of wind-dependent species. Pelagic seabirds, in particular, are wide-ranging predators that rely extensively on wind to move at low costs between breeding and foraging sites and are affected by wind pattern changes.
Ocean circulation[1,8,13,14,32-45] The Southern Ocean is highly dynamic, connected on a circumpolar scale around the Antarctic continent and characterized by many fronts, inter-frontal zones, eddies and gyres. *Properties of ecological importance include:*	Southern Ocean ecosystem dynamics are heavily influenced by the ACC and its frontal systems. The frontal regions differ from other parts of the ACC due to higher phytoplankton concentrations and primary production rates.

Connectivity: The Antarctic Circumpolar Current (ACC) (the dominant component of Southern Ocean circulation) links the major ocean basins, and together with the Antarctic Coastal Current connects physical and biological processes. Frontal locations and dynamics: Fronts are transition zones where properties such as temperature, salinity or nutrient concentration change rapidly, thereby delimiting areas with distinct physical, chemical, and biological characteristics. Fronts are often associated with current jets. Eddy and gyre structure and locations: Eddies and gyres are circulating bodies of water. Eddies are typically short lived (weeks to months; though some may have a much longer duration) and are the result of turbulence. They are commonly formed from ocean fronts. Gyres are persistent large scale features often caused by the interaction of wind and the Coriolis effect.	The highly connected, advective nature of the system has a vital role in productivity and in the dispersal of numerous species at different life history stages, e.g. transport of post-larval krill. Fronts, eddies and gyres influence biogeochemical cycling (mixing and concentration of nutrients, including bringing nutrient-rich deepwater to the surface); primary production (e.g. eddies and gyres concentrate productivity in particular "hotspots"); predator-prey assemblages are closely linked to the different frontal zones; dispersal and retention (e.g. gyres have a role in retention of krill and larval fish); recruitment; provision of suitable habitat/habitat zonation; and access to foraging grounds/foraging opportunities (e.g. dynamics of frontal structures drive at-sea foraging strategies for air-breathing predators and sea birds).
Mixed surface layer depths (MLD) [1,46,47] In the Southern Ocean, intense winds and extreme buoyancy fluxes create some of the thickest mixed layers on Earth. *Properties of ecological importance include:* Thickness, timing and position (including depth): The mixed layer at the surface of the ocean is the gateway for all exchanges between the air and the sea. Important in heat, carbon and nutrient distribution and budgets, and influences light availability.	The oceanic MLD is a major controller of primary production. Deeper mixed layers bring nutrients to the surface but can be unfavourable for phytoplankton growth due to effects on irradiance. The MLD also affects access to prey for diving species.

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