FISH 310

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Scyphozoans in the diet of penguins: Adaptive and/or opportunistic response to increased jellyfish abundance driven by climatic change, or persistent long-term source of prey?

Climatic change will have varying degrees of influence across environments and biota, but ocean warming trends are especially concerning and increasingly evident in polar regions. Trends toward declining pH, resulting in a more acidified ocean, are particularly problematic for species that utilize calcium carbonate in the production of their shells and exoskeletons, and species that rely on these organisms as a prey source. While many species will struggle to adapt to changing environmental conditions, scyphozoans (true jellyfish) are predicted to succeed in a more acidified environment. The ecological implications of this increase in abundance are yet to be understood. Here, I propose a preliminary investigation to determine whether the inclusion of scyphozoans in the Adélie penguin diet is a dietary shift in response to increased jellyfish abundance, or a long-term, persistent source of prey, using stable isotope analysis. This research will provide improved understanding of the role of scyphozoans in the Antarctic food web and will explore the ecological implications of the climate-associated rise of jellyfish.

Introduction

Scyphozoan “jellyfishes” have long been considered a successful organism, due to their low energetic costs given their planktonic lifestyle, their lack of predators and high water content. Jellyfish are not typically included as an important links in ocean food webs and are often considered to be energetic "dead ends" (Arai 2005; Marques at al. 2016). Long thought to be an undesirable source of prey due to their gelatinous composition, low nutritional value, and stinging nematocysts, they have been recognized as important in the diet only of specialists, like certain sea turtle species (Heaslip et al. 2012).

The nutritional composition and value of jellyfish is largely unstudied, and limited only to minimal exploration of their nutritional value for human consumption. Given their predicted success in an acidified environment, the question of whether jellyfish can serve as a viable food source for many species, including humans, is a consideration that is largely unexplored. Despite their presumed lack of nutritional value (Arai 2005), jellyfish do contain carbon and protein (particularly gonads). The gonads and arms of jellyfish contain approximately five times more energy than the bell tissue (Doyle et al. 2007) and the gonads are particularly of high nutritional value with an abundance of amino acids (Yu et al. 2014). In a study that considered the amino acid profiles of three different scyphozoan species, all exhibited almost full amino acid profiles (with some slight variation across sampled species, however the absence of tryptophan was noted in all sample species), which are natural compounds necessary for all biological processes (Leone et al. 2015). Furthermore, scyphozoans have demonstrated antioxidant ability, collagen, peptides and other bioactive macromolecules, with clear potential as a food source with health and medicinal benefits: a "nutraceutical" (Leone et al. 2015).

Cyanea spp. scyphozoans were found to be a prey source of the little penguin (*Eudyptula minor*), which inhabits coastal regions of temperate latitudes, after penguins were fitted with video data loggers (Sutton et al. 2015). Observation revealed that jellyfish (including both whole small jellyfish and inner portions of larger jellyfish including gonads), were more frequently targeted by little penguins on ascent rather than dives, suggesting that jellyfish might not be a preferred prey source but instead, consumed opportunistically when other prey are unavailable.

Antarctic krill (*Euphausia superba*) is the base of the Antarctic food web and the staple prey of most vertebrate species of the Southern Ocean, including penguins. However, a decrease in pH and a more acidified ocean will negatively affect krill, which have a calcareous exoskeleton, and species that depend on krill as their main source of prey. In contrast, a decrease in pH is predicted to be of benefit to gelatinous organisms such as cnidarians, who are anticipated to thrive in a changing ecosystem that will promote a more gelatinous state. (Richardson et al. 2009) A consequence of human-induced warming resulting in climate change is the proliferation of jellyfish, amounting to large scale aggregations of jellyfish known as blooms that will negatively affect the ecosystem (Richardson et al. 2009). It is not fully understood the extent to which the reduction of species with calcareous exoskeletons and the rise of gelatinous organisms will negatively change the ecology of the oceans, however it is predicted to be disastrous and have extensive cascading impacts. For species such as penguins, it is unknown whether they will have the capability to adapt to the loss of their traditional prey, or whether they will fall victim to be being indirectly impacted by climatic change by an inability to adapt.

DNA-based scat analysis of Adélie penguins found cnidarians and ctenophores in relatively high proportions in comparison to krill, suggesting there may be potential for Adélie penguins to shift prey when preferred options of krill and small fish are scarce (Jarman et al. 2013). This suggests there may be an assemblage-level trophic overlap between scyphozoans and small fish, indicating a shared niche (Naman et al. 2016) and the potential for jellyfish to occupy the same role in food webs as small, lower trophic fish. Evidence for such assemblage-level trophic overlap was revealed in Puget Sound, where freshwater inputs were found to influence the ecosystem and trophic structure, by altering the prey base for predators (Naman et al. 2016); freshwater input from the Antarctic ice cap might serve a similar role in influencing the structure of the Antarctic food web. Scyphozoans are both predators and prey (Arai 2005), and species that predominantly or opportunistically prey on scyphozoans may serve to control jellyfish abundance through top-down regulation (Marques et al. 2016).

Stable isotope analysis has been a relatively recent way in which to investigate the diet of organisms by using fossilized or fresh samples of blood, feathers, eggshell, and/or bone (Emslie and Patterson 2006). The samples from preserved tissues from individuals that died long ago can indicate dietary niches through analysis of deposited carbon and nitrogen isotopes (McCutchan et al. 2003), revealing extensive historical information about species and their dietary niches. The fossilized eggshells of Adélie penguins dating back to approximately 38,000 years were examined through stable isotope analysis and indicated that across this time series there was one significant and abrupt shift in diet approximately 200 years ago (Emslie and Patterson 2006). This is approximated with the major ecological shift following heavy periods of whaling and a reduction of baleen whales, marine mammals that were the predominant predators of Antarctic krill. Thus, the near-eradication of a higher trophic species that previously occupied the dietary niche of feeding upon Antarctic krill then became available for penguins to occupy instead, and so Adélie penguins shifted prey from small, low trophic fish to krill, supporting the krill surplus hypothesis (Emslie and Patterson 2006). In considering the observation that Adélie penguins are consuming scyphozoans that were not previously known to be an item of prey, the inclusion of scyphozoans in the diet of Adélie penguins in past stable isotope analysis may very well have been overlooked and requires further investigation.

Observation and Theoretical Motivation for Research

Polar regions exhibit low species diversity and limited resource availability; thus, short food chains exist and species tend to specialize in a particular prey type, developing dietary niches. Dietary niches limit the availability of predator-prey interactions, causing predators to become specialists. However, due to the remote and harsh nature of polar regions, observation and, as a result, understanding of species in icy habitats is limited. Therefore, knowledge on penguin species that are exclusive to the Antarctic region is not entirely extensive and could serve to be further studied.

Adélie penguins (*Pygoscelis adeliae*), a vertebrate species of Antarctica were observed consuming scyphozoans for the first time, as a result of a study where video data loggers were fixed to the penguin to observe behaviour and diet (Thiebot et al. 2016). Specifically, Adélie penguins targeted jellyfish of the species *Diplulmaris antarctica* that exhibited prominent sex organs that were visible in comparison to those that were not visible or indistinguishable. (Thiebot et al. 2016). In the 28 predatory events where *Diplulmaris antarctica* exhibited visible gonads, Adélie penguins attacked 100% of time and a Fisher's exact test for count data produced a P value of <0.001, indicating a statistically significant relationship between gonad visibility and predation (Thiebot et al. 2016). In contrast, when gonads were not visible (11) only one predation event occurred, and when gonads were indistinguishable (40), there were 25 predation events (Thiebot et al. 2016). Adélie penguins appeared to attack the bell edge of *Diplulmaris 5antarctica*, often further shaking the jellyfish and fragmenting it potentially for easier consumptions of specific body components (Thiebot et al. 2016). The preference for predating upon scyphozoans with visible gonads may in part be related to the greater nutritional content than the gelatinous bell. It appears that Adélie penguins consume jellyfish as an alternative prey source to their preferred prey of Antarctic krill, however it is unknown whether this is an opportunistic dietary shift resulting from trophic changes attributed to environmental conditions, or whether the inclusion of scyphozoans in the diet of Adélie penguins has been previously overlooked due to lack of observation, thus prompting several questions:

Questions:

1. Is this a new source of prey, or have scyphozoans been an unrecognized item of prey in the diet of Adélie penguins?
2. If previously unrecognized as prey, what is the time frame over which scyphozoans have been present in the diet of Adélie penguins?
3. If scyphozoans are a new source of prey for Adélie penguins and this is a dietary shift, what are the drivers of the shift and are they attributed to warming effects of climatic change? Is there an increased availability of jellyfish and/or a reduced availability of the preferred prey of Antarctic krill?

Hypotheses

I hypothesize that the presence of scyphozoans in the diet of Adélie penguins is a recent adaptive and/or opportunistic prey shift arising due to increased jellyfish abundance and/or reduced availability of preferred prey driven by climatic change, and that this shift occurred between the last abrupt shift in prey approximately 200 years ago and the present time.

Alternatively, if scyphozoans are found to be an established and persistent prey source of Adélie penguins, this indicates there is much to be understood regarding the functional role of jellyfish in foods webs, especially the Antarctic ecosystem. A more holistic understanding of food webs inclusive of scyphozoans as prey (new or existing), especially in warmer and more acidified oceans, will be integral for precision in future ecosystem model predictions.

The results arising from both hypotheses will reveal a previously unknown understanding of the role of jellyfish and its predators in the Antarctic food web as warming trends continue to alter the ecosystems within which they exist.

Experiment Design

I propose conducting stable isotope analysis on collections of Adélie penguins housed within museums and experienced life history stages within the last 200 years to determine whether scyphozoans were present in their diet, and comparing the values to stable isotope analysis conducted on living Adélie penguins that are currently feeding upon scyphozoans.

Museums house extensive avian collections that have been obtained over broad swathes of time and space, and ornithology databases have in excess of >1000 Adélie penguin samples. Particularly, there are significant samples of Adélie penguins within Australia given its proximity and relationship with the Antarctic region. This serves as a valuable resource as it enables a snapshot of the life history of organisms across varying time periods and can be conducted on the feathers and/or bone of preserved samples to determine diet. This research requires access to museum collections that house preserved specimens of Adélie penguins from the last 200 years so that feather samples can be obtained and stable isotope analysis can be conducted to determine whether the presence of scyphozoans in the Adélie penguin diet is new, and may be attributed to climatic changes, or whether it has been persistent over of time. It would be ideal to conduct this experiment on Adélie penguins that were obtained across varying spatial ranges of the Antarctic, to determine that there is no dietary bias in geographic region or colony.

For the stable isotope analysis, a determination of isotopic composition and trophic position for both predator and prey will be necessary:

Stable isotope composition on *Diplulmaris antarctica* must first be established to determine value and trophic transfer, as it is not a well studied species (Thiebot et al. 2016). Fresh specimens will need to be collected and cultured, employing already established specialized subsurface techniques (Raskoff et al. 2003) on the gonads, as different body components have varying isotopic values (Pitt et al. 2003). By determining the stable isotopic values in *Diplulmaris antarctica,* this will provide indication for the trophic transfer when ingested by Adélie penguins and establish the enrichment the tissue of samples of Adélie penguins are analyzed.

It could be foreseen that a limitation of the research may be a lack of understanding of the complexity and function role of scyphozoans in ecosystems, thus the trophic levels that jellyfish occupy may vary. Jellyfish have been found to not be a single functional group due to variance in trophic levels as established by stable isotope analysis (Fleming et al. 2015), therefore stable isotope values of carbon and nitrogen for cnidarian species would vary according to their trophic position as established by their diet and size. By obtaining the stable isotope composition for the *Diplulmaris antarctia*, an isotopic value range can be established and trophic transfer can be calculated after conducting stable isotope analysis on Adélie penguins tissue samples and analyzing the results.

Given that polar food chains are relatively short, dietary links between trophic levels should be relatively well established.

Once stable isotope composition and analysis on samples of predator and prey has been completed, the data will be analysed using mixed modelling for further understanding.

Anticipated Results

If Scyphozoans are found to have been present in penguin diets, it could be attributed to a lack of observation and understanding of a species that utilizes the habitat of such a remote region as Antarctica. However, if findings indicate that the shift of ingesting jellyfish and their respective gonads as a new prey source, this would be an important realization for species adaption. This knowledge in broad terms, would indicate that species with specialized niches in unique environments may in fact be able to adapt to a rapid changing climate, and further assert the importance of scyphozoans in food webs.

Discussion

Through conduction of this experiment, there will be a greater understanding of two groups of organisms: Adélie penguins, with potential for a broader understanding of penguins; and cnidarians.

While this research will specifically examine the role of role of scyphozoans in the diet of Adélie penguins and their role in food webs, further research can be conducted on the niche width of Adélie penguins. It could be possible that the niche width of penguins is greater than once understood and not just limited to Antarctic krill and small, lower trophic fish – in which case this may have greater significance not just for penguins but for many species across the polar regions that are most susceptible to the imminent ecological shifts resulting from climatic change. If a greater niche width is established, ecological modelling predicting the sensitivity of polar species as warming trends continue to increase will need to be adjusted. Furthermore, selected species such as Adélie penguin may be excluded from being a species of high risk.

Further studies could investigate whether this dietary inclusion is exclusive to the Adélie penguin, or whether other penguin species are similarly preying upon scyphozoans and their distinct body components.

For species that specialize in feeding on scyphozoans like the sea turtle, they serve to play a top-down predatory role in the proliferation of jellyfish blooms and somewhat regulating the explosion of their abundance. If Adélie penguins are found to either be an established predator of scyphozoans, or a new predator, they serve to fulfill the same top-down predatory role as sea turtles in the Antarctic ecosystem which would be an important revelation for climatic change modelling. This consideration is unlikely to previously have been factored into predictions of jellyfish and their expansions in the ecosystem, suggesting that a proliferation may not be as extensive as once believed.

Pertinently, this research will consider the role and importance of scyphozoans in the Antarctic ecosystem and food web, and potentially give rise to investigation their role in other food webs and ecosystems of which they are most often overlooked. Their value as an individual species and in predator-prey relationships across varying environments requires establishing to greater understand their ecological importance. Considering that the effects of climate change are most rapid and evident at the polar regions, an understanding of scyphozoans is most imminent for understanding the current and future states of the Antarctic ecosystem and its organisms.

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