Critical literature review

Sea ice algae no more?

The importance of sea-ice algae to the Antarctic marine ecosystem and the potential impact of climate change on this ecosystem.

Abstract

Primary productivity is an essential part of all ecosystems. Primary producers are important for starting the carbon cycle. In areas such as the Antarctic which is known to face climate changes, understanding how these changes will effect primary producers is of high importance. Wider ecosystem effects also needed to be considered. The main primary producer in sea ice communities is sea ice algae. Dramatic cooling or warming events will result in changes in sea ice extent. These changes could potentially have negative effects on sea ice algae populations and the wider marine ecosystem. More work is needed to fully predict the potential effects of Antarctic warming and cooling on the wider marine ecosystem

Key words

Sea ice, sea ice algae, primary productivity, climate change, Antarctica

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Introduction

Antarctica and the Southern Ocean

The continent of Antarctica is an isolated and harsh area within the Southern Ocean at the bottom of the planet. The continent itself is 14 million km^2 and is divided into two areas, West and East Antarctica, by the Transantarctic mountains (Fitzgerald et al. 1986). All year round the majority of the continent (97%) and some of the oceans surrounding it are ice covered (Hund 2014). The West and East Antarctic ice sheets are responsible for most of the ice coverage, along with sea ice in the coastal regions (Hund 2014). The ice sheets of Antarctica contain about 60% of the world's fresh water (Hund 2014). The marine region of the Antarctic extends out to 60°S and is separated from the surrounding oceans by the circumpolar current. Within the circumpolar current there is the polar frontal zone. The waters around Antarctica can range in temperature from 8°C in summer to -15°C in winter (Eicken 1992). The Southern ocean ecosystem is very a complex and intricate system (Morgan-Kiss et al. 2006, Garrison 1991). Ocean primary production all together makes up around half of the global biospheric production with permanently cold ecosystems itself making up one of the largest biospheres on the planet (Henson et al. 2010, Morgan-Kiss et al. 2006). Primary production is the synthesis of organic molecules and compounds from different carbon sources. In marine ecosystem carbon is in its aqueous form. Sea ice plays a large role in the primary productivity of the southern ocean. Detecting the impact on ocean productivity is extremely important, in particular the effects of climate change on sea ice populations around Antarctica.

Sea ice

Sea ice is one of the most prominent features of the Southern Ocean as more than 40% of the ocean is covered in sea ice (Morgan-Kiss et al. 2006, Lizotte 2001, Garrison 1991). It is mainly located in the polar frontal zone. In winter the sea ice covers $20x10^6$ km^2 and reduces in summer to only cover $4x10^6$ km^2 (Eicken 1992, Lizotte 2001, Garrison 1991). During winter the sea ice is 50% greater than the total area of the continent itself (Lizotte 2001). There are many different types of sea ice, some classed on age others classed on relationship to the shoreline (Eicken 1992, Garrison 1991, Garrison et al. 1986). Fast ice is when the ice form is attached to the shoreline. Drift ice is when sea ice forms offshore and is free to move (Garrison 1991). The classification according to age is as follow. New/young or nilas ice is recently frozen sea water that does not make up a solid ice form (Garrison 1991). First-year sea ice is thicker than young ice but has not undergone more than one year of growth (Morgan-Kiss 2006). The final age classification is old or multi-year ice which is usually over 2 years old and 1m thick (Arrigo and Thomas 2004, Thomas and Dieckmann 2002). Sea-ice provides a complex habitat for many microorganisms (Morgan-Kiss et al 2006, Curran et al. 2003, Lizotte 2001, Eicken 1992, Garrison et al. 1986). Sea ice extent is seasonal, being at its greatest in November and lowest in February (Lizotte 2001, Arrigo et al. 1997). Primary producers are particularly important in cold ecosystems as they are the essential inorganic carbon fixation and autotrophic energy production (Morgan-Kiss et al. 2006, Lizotte 2001). These primary producers such as algae, use sea ice as a habitat and provide higher trophic levels with essential carbon and other nutrients (Morgan-Kiss et al. 2006, Thomas and Dieckmann 2002, Lizotte 2001).

Algae as a primary producer

Algae are small lower plants which lead a relatively simple life. Algae can be found as mats in ponds, lakes or rivers (Nemjova et al. 2009, Schagerl et al. 2008, Brawley et al. 1992, Kratz et al. 1955, Burlew 1953). Or in some cases algae is found growing terrestrially in soils (Nemjova et al. 2009, Schagerl et al. 2008, Brawley et al. 1992, Kratz et al. 1955, Burlew 1953). Algae is found in a range of aquatic environments ranging from marine, estuarine, freshwaters and in below zero waters such as found in Antarctica (Schagerl et al. 2008, Lizotte 2001, Brawley et al. 1992, Kratz et al. 1955, Burlew 1953). The most studied algae in Antarctic is sea ice algae (Arrigo and Thomas 2004). Sea ice algae is an essential primary producer within the marine ecosystem. Sea ice algae populate all the different classifications of sea ice, with communities are most commonly found on first year sea-ice as light is more accessible than multiyear sea ice (Lizotte 2001). It provides essential nutrients such as iron and carbon to higher trophic levels. Even other primary producers such a phytoplankton relay on algal populations as a nutrient provider. An algal blooms key role like many other plants is to photosynthesise, respire and reproduce (Burlew 1953). Algal growth is mainly dependent upon nutrient availability, salinity and temperature (Kratz et al. 1955). In cold temperatures such as the southern ocean surrounding Antarctica algal populations are found to contain adaptations which allow them to survive at low temperatures (Morgan-Kiss et al. 2006, Arrigo and Thomas 2004). The main adaptation seen in sea ice algae is the ability to thrive in environments low in light, such as that on the underside of sea ice where light availability is less than 1% (Morgan-Kiss et al. 2006, Arrigo and Thomas 2004). This is possible due to alterations in the electron transport chain and photosynthetic processes themselves, resulting in less light being needed for growth (Morgan-Kiss et al. 2006). Sea ice algae experience large blooming events during the transition from winter to spring (Morgan-Kiss et al. 2006). During summer is when sea-ice algae populations are that their highest, this links in with the height of productivity for the southern ocean. Due to these findings sea ice algae has been suggested to be the key primary producer of marine Antarctic ecosystems. Most marine animals in the Antarctic show a varying amount of metabolic cold adaptation. Such metabolic cold adaptation may involve an increase in standard metabolic rate (SMR) to counteract the Q^{10} effect in place due to the low temperatures of the water (Somero et al. 1968). Due to the metabolic cost involved with an increase in SMR many Antarctic marine animals have a lower metabolic scope for activity. Sea ice algae provides a 2D food source, instead of the 3D source of the ocean itself, which allows these marine animals to use less energy in foraging resulting in more energy allowance for survival and reproduction. Changes in the climate, such as warming, have the potential to threaten these sea ice algae communities by inducing changes in sea ice structure and extent which may result in disastrous effects on the wider marine ecosystem.

Climate change effects on sea-ice and productivity

Warming in Antarctica

Warming of Antarctica has been observed for many years (Vaughan et al. 2003, Oppenheimer 1998, Garrison 1991). This warming, particularly in the Antarctic Peninsula has caused melting of the Antarctic ice sheets and in some cases of sea ice also (Vaughan et al. 2003, Oppenheimer 1998). Changes in sea ice extent has been observed since the 1970s (Turner et al. 2009). Turner and colleagues suggested that the appearance of the ozone hole and an increase in greenhouse gas emissions has led to this change in sea ice extent (SIE) (Turner et al. 2009). Sea ice itself plays an important role in climate control, ocean atmosphere heat exchange, ocean circulation and the productivity of the marine ecosystem (Arrigo and Thomas 2004, Curran et al. 2003). Productivity is commonly measured by the use of MSA or chlorophyll concentration methods. Methansulphonic acid (MSA) is used as an indicator of biological activity within ice (Curran et al. 2003, Wolff et al. 2003). When looking at ice cores to gain insight into productivity in the past the concentration of MSA is used. When determining the productivity of present sea ice communities the concentration of chlorophyll is used (Arrigo et al. 1997, Brock and Brock et al. 1967). Chlorophyll is an organelle important in the photosynthetic biochemical pathway in primary producers. It is within chlorophyll that the transfer of light into energy occurs. Due to sea ices' importance in primary production it is not surprising that there is evidence from ice core samples that changes in SIE had great effects on the primary productivity of the southern ocean and the wider ecosystem (Curran et al. 2003). This decline in productivity and sea ice was linked with a decrease in Emperor penguins (Curran et al. 2003, Barbraud and Weimerskirch 2001). Warming of the Antarctic and its effect on organisms is a current issue being investigated by many scientists, but the potential cooling of Antarctic may also have negative effects of organisms.

Potential effects of warming on sea-ice and productivity

If Antarctica continues to warm there will be a dramatic impact on sea ice communities and the overall marine ecosystem. Warming will have an effect on SIE. If sea ice is present for shorter periods of time throughout the year sea ice algae will have a shortened period for growth. In correlation if sea ice does not completely disappear, warming may have a beneficial impact on sea ice algae communities. With a warmer climate the occurrence of multiyear ice will decrease and the first year will increase. This would provide the alga with environments richer in light. As light is the most important limiting factor to algae growth, higher light intensities may result in more algal blooms. In warmer weather more melt and flooding of sea ice surface occurs resulting in release of more nutrients (Arrigo and Thomas 2004). Significant sea ice loss has been observed in the arctic (Post et al. 2013). As primary producers depend on sea ice as their habitat once sea ice extent reduces so will productivity. Before this reduction in productivity an increase may be observed due to increased light penetrating through the thinning sea ice. As light is an essential factor for all primary producer growth, when it is in excess it is likely to observe a peak in productivity. In recent years a study was undertaken measuring primary production via the use of chlorophyll concentration (Arrigo et al. 1997). This study by Aggrio et al. showed that productivity was highest in months with greatest light and heat penetration through the sea ice, those months being December, January and February (Arrigo and Thomas 2004, Arrigo et al. 1997). These months also had some of the lowest extends of sea ice. Once light is dimmer in later months such a April productivity drops again ***refer to figure 1 (Arrigo et al. 1997).*** This supports the idea that if sea ice thins due to climate change there may be a surge in productivity before complete loss ensues. With loss of SIE an increase in UV radiation could pose a threat to sea ice algae populations. Lower protection from UV radiation may led to DNA damage within sea ice algae populations resulting in a lack of ability for these populations to successfully survive (Arrigo and Thomas 2004). Warming of the Antarctic may have some beneficial effects to the ecosystem at the beginning but if warming continues drastic changes to the ecosystem may be observed.

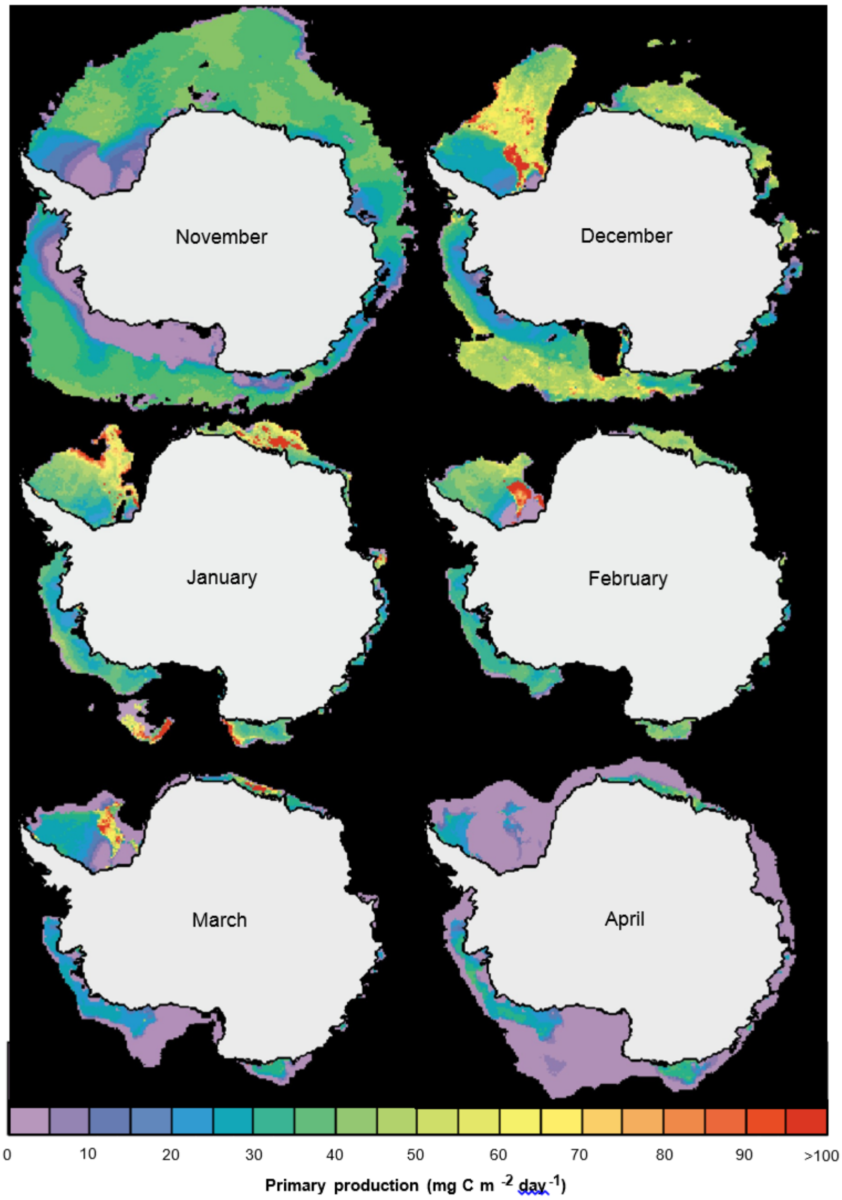

Figure 1 (Adapted from Arrigo et al. 1997)
Measurement of sea ice productivity via chlorophyll concentration methods over 6 months. Productivity is greater in months with less sea ice cover.

Potential effects of cooling on sea-ice and productivity

If cooling of the Antarctic occurs SIE will likely increase. This along with warming could also pose some threats to the marine ecosystem. In a cooled climate multiyear ice is likely to become the norm. Sea ice may stay around for years on end eventually growing thicker and thicker due to the cold environment. As productivity is not directly correlated with SIE an increase in SIE may or may not have a negative impact on primary production. Sea ice algae blooms are most commonly found in young sea ice rather than multiyear sea ice due to light exposure conditions. If the trend shifts for there to be more multiyear sea ice rather than young/ first year sea ice this could lead to a production decline in productivity. Nutrient conditions may also differ. Release of biological matter upon ice melt is an important event in sea ice cycle (Arrigo and Thomas 2004). With less sea ice melt due to the cooler environment less nutrients such as iron will be released from sea ice and other surrounding ice stores resulting in a decrease in nutrients for primary producer growth. It is hard to find literature on this potential cooling effect however from previous cooling/ice ages it is evident that extreme cooling does have a huge impact on organisms of all different sizes and ecosystems.

Whether it is loss in productivity due to increase or decrease in SIE there is the potential for this loss to have an impact on the wider ecosystem.

Loss of productivity effects on the wider marine ecosystem

Sea ice algae is a crucial part of the southern ocean marine ecosystem. It is the key primary producer essential for carbon recycling and nutrient transfer. Sea ice algae primary productivity may be lost due to climate change effects, or extreme warming or cooling. Loss of primary producers have detrimental effects on the wider ecosystem. Without primary producers to convert carbon into energy and other essential nutrients ecosystems will quickly fall apart.

Role of primary producers

Primary producers provide higher trophic levels with essential nutrients for growth. They take carbon stores from the surrounding environment, either carbon in the air from animals exhaling or in the form of dead organic matter in aqueous environments from dead organisms. This is done by oxidation and reduction of chemical compounds powered by energy made through photosynthesis. Almost all organisms are reliant on primary producers. They can either be directly reliant such as Krill which feed directly on primary producers such as algae (Arrigo and Thomas 2004, Thomas and Dieckmann 2002, Eicken 1992, Garrison 1991, Hopkins 1987). Or they can be indirectly reliant, which are those higher trophic level organisms such as seals which feed on Krill (Arrigo and Thomas 2004, Eicken 1992, Fraser et al. 1992).

Impacts on wider ecosystem

As every organism is in some way reliant on primary producers it is no surprise that loss of primary production will have a whole ecosystem impact. There is a very good example of these kind of impacts in the Arctic (Post et al. 2013). Sea ice extent reduced resulting in a reduction in the primary producer's phytoplankton and algae (Post et al. 2013). Many species depended on these primary producers either as a direct or indirect source of energy.

This led to a collapse of the zooplankton communities which directly relied on these primary producers (Post et al. 2013). The loss of zooplankton then effected higher trophic levels such as cod which continued to effect other predators such as killer whales (Post et al. 2013). This could potentially also occur in Antarctica. Many organisms such as Krill and copepods rely on sea ice algae as a food source (Arrigo and Thomas 2004, Garrison 1991). If sea ice algae populations decrease so will Krill and copepods which will effect higher trophic levels such as fish, seals and penguins. In the Antarctic there has been a reduction in those penguin species reliant on the ocean around sea ice to find prey when there has been a decrease in primary production seen by MSA studies (Curran et al. 2003). Cooling and or warming of the Antarctic has great potential to cause ecosystem collapse.

Conclusion

Extreme changes to the climate in Antarctica could pose huge threats for its inhabitants. Warming has been observed over the past decade, particularly at the Antarctic Peninsula. Warming of the Antarctic will have dire effects on SIE. Initial warming may help to stabilise sea ice cover, but continued warming will lead to its collapse. Changes in SIE will cause unpredictable changes to sea ice algae communities. Sea ice algae communities may suffer greatly from a reduction or increase in SIE. Reduction of sea ice alga populations will have an impact on the wider ecosystem and energy recycling. Without primary producers to recycle carbon from the environment back into the ecosystem, the ecosystem may be prone to collapse. This ecosystem collapse has been observed in the Arctic. More studies need to ensue to predict the potential effect of changes in SIE on the wider ecosystem. Better methods for measuring productivity would enable more accurate predictions. The creation of a computer model which could simulate changes to SIE and productivity would help support the accuracy of such predictions. Until then we can only take guesses at what may occur and hope warming does not continue.

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