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Critical Literature Review (ANTA602)

Title: The Southern Ocean Toothfish Fishery – Conflicting evidence highlights uncertainty in fishery management.

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Abstract

The Southern Ocean Toothfish fisheries, -managed by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)- are constantly examined for their sustainability and greater ecosystem impacts. Despite fish biology and ecosystem interactions having been investigated since the establishment of CCAMLR in 1982, the data produced is yet to allow scientists to draw comprehensive conclusions about the impact and true scale of the exploitation of fisheries or the trophic interactions of fish populations with marine mammals and the wider ecosystem. Although a vast amount of literature explains some of the life histories and biology, there is still not enough known about toothfish, specifically; juvenile toothfish survival rates, juvenile distributions, geographic influences, water circulation influences, migrations and movements, to allow us to understand the importance of this key species in the Antarctic ecosystem. This review highlights new research that identifies some of the unknowns about the fish biology, challenging CCAMLR's views of a sustainable fishery. This review also identifies gaps in the literature that proves that the vast connection to the ecosystem cannot be fully understood with improved knowledge.

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Introduction

The Patagonian toothfish (*Dissostichus eleginoides*) and Antarctic toothfish (*Dissostichus mawsoni*) are currently targeted by 13 licensed fisheries, which are managed in three large areas within the Southern ocean by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (CCAMLR, n.d.). Both species are highly sort after for commercial markets focused on high-end restaurants and prices have been seen to range between USD$10.00/kg to over USD$50.00/kg (Grilly, Reid, Lenel, & Jabour, 2015). These prices have increased dramatically since 1999 and are believed to be due to a reduction in trade volume, average individual catch size and general availability (Abrams, 2014; Agnew, 2000; Ainley et al., 2013; Grilly et al., 2015).

Catch records for the Patagonian toothfish have been recorded by CCAMLR since 1977, however Antarctic toothfish records only date back to 1998 (CCAMLR, n.d.), and since 1998 the Antarctic toothfish catch numbers have increased approximately ten times the original catch numbers (CCAMLR, n.d.). Records and observations from early literature highlights a substantial lack of recording in historic takes and also describes a substantial number of illegal, unreported and unregulated (IUU) operations during the earlier years (Agnew, 2000). Recently, efforts by CCAMLR have resulted in vast reductions in IUU fishing and since 2010 illegal fishing takes are though to have declined to negligible amount (Dodds, Hemmings, & Roberts, 2017; öSterblom & Bodin, 2012).

A number of non-commercial Antarctic research and fisheries scientists have been questioning the management of the Southern Ocean toothfish fisheries and have highlighted that the fishery might not be in the best interest of the greater ecosystem due to a number of overlooked and/or less understood issues (Ashford, Dinniman, & Brooks, 2017; McCormack, 2016). It has been suggested that a lack of understanding could be due to the fact that most of the CCAMLR findings relating to the fishery are unpublished in the primary literature (Hanchet et al., 2015).

The majority of the scientific literature suggests that both species are slow growing and previous knowledge indicates that cold environments reduce activity and growth rates in most fish (Pörtner et al., 2001). However, this is disputed by CCAMLR and comparisons are often drawn between other fishery species to make a point rather than a comparison to all fish species.

Patagonian toothfish are estimated to reach spawning age between 8- 10 years old and Antarctic toothfish are thought to reach maturity slightly later, at 13 to 17 years old depending on their sex (NIWA, n.d). Both species of toothfish are thought to grow to more than 2 metres in length and mature fish can weigh over 150kg, but growth rates and age at maturity estimates vary greatly, more so for the Antarctic toothfish.

Toothfish biology and their life history has proven a contentious issue in recent years (more so for the Antarctic toothfish than the Patagonian toothfish) (Ashford et al., 2017) as they are fundamental measures used in fisheries management and aid in population assessments. Findings relating to the Antarctic toothfish reproductive cycles and their age at maturity show inconsistencies with conclusive evidence proving hard to find due to a lack of publications that are confident in their conclusions. Even less evident are publications that produce findings on juvenile toothfish and the biology surrounding this crucial part of their life (Ashford et al., 2017). This in part is due to the difficulties of obtaining specimens that are at a spawning stage or juvenile age, as it is thought that breeding occurs during winter under the sea ice (Ainley et al., 2013) and juveniles may migrate during early life stages (Brigden, Marshall, Scott, Young, & Brickle, 2017). Very recent reviews have suggested that life history studies have been relegated completely by management issues, lessening advancements (Ashford et al., 2017).

Ambiguities in fish biology have raised questions about the amount and quality of knowledge used to make successful estimates of biomass and stock sustainability for the toothfish fishery in the Southern Ocean.

The importance of the toothfish in the Southern Ocean is undefinable as its role as predator and prey cannot be replaced in the Southern Ocean ecosystem by similar species. The unique environment in the Southern Ocean meant that through evolution, toothfish (and a very limited number of species within the lineage) were able to radiate into most benthic and pelagic environments, filling these unique niches (Ainley et al., 2013) and defining their role as a key component of the Antarctic ecosystem. The toothfish have been described as top predators in some areas of the Southern Ocean (McArthur, Butler, & Jackson, 2003) and also crucial prey items for whales, seals, and colossal squid (Ainley & Siniff, 2009). Flow on effects of the removal of these key species are still recently being researched.

In this review I have investigated the current contradictions in knowledge surrounding the toothfish fishery in the Southern Ocean. Numerous conflicting views about the fishery have caused concerns and raised questions about its feasibility. Hypothetical information regarding fish biology and hypothesised lifecycles has caused a variety in opinions about the appropriateness of the fishery and further contradictions about the effect experienced by marine mammal has caused confusion about its overall impact on the ecosystem.

Discussion

In the 1970-80s the Southern Ocean fisheries were unregulated and unpatrolled, quickly encouraging questions about long term sustainability and influencing the decision to establish CCAMLR in 1982 (CCAMLR n.d.). The goal was to establish a sustainably managed fishery in the Southern Ocean that focused on an ecosystem based management approach. Fisheries management estimates catch limits based on the individual targeted species biology - generally estimated as the growth rates, rate of reproduction and number of viable eggs - known as fecundity (Murua et al., 2003). However, successful fisheries management takes into account both the biological and physical interactions that can affect the overall fecundity outcome (Murua et al., 2003). These important biological processes help build fisheries models by estimating total biomass each year and apply catch limitations such as, Maximum Sustainable Yield (MSY), Total Allowable Catch (TAC) or Harvest Control Rule (HCR) (and more) (Dankel, Skagen, & Ulltang, 2008).

CCAMLR use the TAC system which is based on information provided by two working groups developed within a CCAMLR Scientific Committee (Abrams, 2014; Dankel et al., 2008; Hanchet et al., 2015). Sustainability is the main focus of the management plan to ensure exploitation does not outweigh conservation (Abrams, 2014) and to do this the management of the fisheries is based on removing 50% of the spawning biomass over 35 years (Salas et al., 2017) . The importance of an in depth understanding of the fish biology reduces error in total biomass assessments/stock assessments (Ainley et al., 2013; Haddon, 2011) and overall ecosystem impacts.

Historically fisheries such as the Atlantic cod or Orange Roughy have seen monumental collapses, due to a poor understanding of fish biology and life history, (Hilborn, Annala, & Holland, 2006; Hutchings & Myers, 1994) causing devastation to ecosystem and economy (Hutchings, 2000; King & McFarlane, 2003). Overfishing of the Atlantic cod, due to the economic rat race, saw catch landings decrease from of 800,000 tonnes a year to less than 150,000 tones in under ten years, causing the eventual collapse of the fishery and decimation of the species (Hutchings & Myers, 1994). Although over fishing played a major part in the fisheries collapse, the lack of knowledge surrounding fecundity meant that the stocks had no chance at survival as the population had insufficient time to replenish stock. This was the most important factor that led to the demise of the Orange Roughy fishery. Assumed knowledge about life cycles, rate of reproduction, age at maturity and juvenile success, was based on hypothetical knowledge and was used to predict biomass and stock assessments which have now been describe as overly optimistic (Hilborn et al., 2006). The fishery proceeded with incomplete knowledge about the life histories, which led to a drastic decline in stocks and a major collapse in the fishery. This incident encouraged a revisit of the science surrounding the fishery before a complete collapse happened (L. R. Pitman, Haddy, & Kloser, 2013). This revisit promoted stock recovery by decreasing TAC to a rate that allowed the stock to grow over time. The fishery is still in a recovering state due to the long-lived nature of Orange Roughy but, encouraged research to understand the fish biology and life history better (L. R. Pitman et al., 2013). Unfortunately due to the low publications surrounding the Orange Roughy and their role in the ecosystem, the immediate impacts of the stock declines were rarely published and the Orange Roughy example was used more as a learning curve for fisheries management (Clark, 1995).

In the last 20 years CCAMLR have been questioned extensively about the feasibility of the toothfish fisheries in the Southern Oceans due to issues surrounding a lack of understanding of the species biology. Most research surrounding Patagonian toothfish life histories is agreed upon, as these fisheries extend outside the Southern ocean and specimens are easily obtainable for research (Collins, Brickle, Brown, & Belchier, 2010), although data on larval and egg distributions are scarce and information on juvenile distributions throughout their early stages are varied.

The more contentious issue surrounds the Patagonian toothfish life histories, which up until very recently have been relatively unknown. This fish was thought to be a long-lived and very slow growing fish due to the environment it lives in, which should have great implications for the fishery, increasing the complexity in population modelling by reducing the rate of stock replenishment (Birkeland & Dayton, 2005). Studies in 2010 have confirmed length and age at spawning (Parker & Grimes, 2010) and since then many other life histories have been hypothesised or confirmed (a detailed breakdown can be found in (Ashford et al., 2017) & (Ainley et al., 2013)). A hypothetical life cycle proposed by Hanchet, Rickard, Fenaughty, Dunn & Williams, (2008) has been cited over 70 times however, since 2010 there have been a number of papers highlighting the inconclusiveness of some of the hypotheses surrounding the reproductive life cycles and highlighted holes in the literature (Abrams, 2014; Ainley et al., 2013; Ainley, Brooks, Eastman, & Massaro, 2012; Ainley, Eastman, & Brooks, 2016; Hanchet et al., 2015). Many of the Antarctic toothfish biology studies now agree that although these hypothesis aren't concrete evidence they are still far from being disproven (Ashford et al., 2017) and instead of being taken as fact should be used as a tool for aiding further understandings of life histories. Throughout reviewing some of the literature, the themes that present themselves often is that insufficient knowledge surrounds juvenile survival rates, juvenile distributions, and geographic and circulation influences (Ainley et al., 2012; Ashford et al., 2012, 2017; Hanchet et al., 2015). It has also been documented that there are major gaps in spawning complexities, success, and egg fertilization due to limitations in data collection (Di Blasi Davide, Ghigliotti, Pisano, Stevens, Vacchi, & Parker, 2017).

The current fishery status is reported as healthy and non-commercial findings are yet to prove otherwise. Annual fisheries reports are produced by CCAMLR extensively covering stock evaluations and management improvements however, when describing CCAMLRs' understandings of life cycles and distributions, the language used is very vague (CCAMLR unpublished, 2016) and often is seen to cite hypothesised lifecycles in a factual way without scepticism.

This raises the question of how confident we should be about the science behind the fisheries management and whether the understanding of the Antarctic toothfish biology is strong enough to establish a sustainable fishery with a "ecosystem based management approach". This issue is of high importance, due to the recent change in the management status of the Antarctic toothfish fishery, from an 'exploratory' fishery (where very low catch numbers are allowed) to a 'precautionary' fishery (with increased catch limits) (CCAMLR n.d.).

A lack in a complete understanding of the fish biology could lead to overfishing and population declines, as seen historically, which would have drastic flow on effects in the Antarctic. The importance of understanding the life histories goes further than the immediate threat to the fish population.

The overexploitation of toothfish, as a result of a lack of understanding of fish biology, would be detrimental to all marine life that have trophic interactions with toothfish as this can cause cascades through the ecosystem. Trophic cascades can be described as either top down (the removal of top predators, or a third or fourth level consumer causing a disruption in the food chain or food web) or bottom up cascades (visa versa) affecting the balance in the ecosystem and displacing food web dynamics (Polis, Sears, Huxel, Strong, & Maron, 2000).

Some researchers are attributing the removal of toothfish from certain areas to the declines in populations of marine mammals (Ainley, Ballard, & Olmastroni, 2009; Ainley & Siniff, 2009; Goldsworthy, He, Tuck, Lewis, & Williams, 2001). This type of research has been looked at to help decide the importance of toothfish to specific species and gauge an understanding of the consequences of removing them. An example of this can be seen by the research carried out in the Ross sea region. A recently described sub species of resident Orca, currently referred to as Ross sea Orca or Ecotype-C (Ainley et al., 2009), are exclusively reliant on the Ross sea Antarctic toothfish as a food source (R. Pitman & Ensor, 2003). Recent studies are seeing declines in this population and are suggested to be due to the reduction in biomass of their food source (Ainley et al., 2009). Other studies have seen similar dependence on toothfish as prey for marine mammals such as Weddell seals in the Ross sea (Ainley & Siniff, 2009). Similar studies in the Macquarie islands have proven that there is no dependency on toothfish for the Weddell seals in this area (Goldsworthy et al., 2001). These different findings cause conflicting conclusions about the toothfish importance in the ecosystem and prove problematic for fisheries management. Geographic location of toothfish seems to have varied impacts on the ecosystem and their intrinsic value is weight differently depending on the availability of another food source.

A very recent study carried out in the Ross sea region, on Weddell seals highlights the fact that, although toothfish might not be a crucial prey item in regards to the individuals survival, the removal of this energy dense prey item could see reductions in the populations' growth rate, reducing populations by >10% per year (Salas et al., 2017). Other effects could see changes in females' ability to regain mass at the end of moult cycles potentially effecting reproduction (Salas et al., 2017). The paper is concluded by relating back to the fisheries management, demonstrating concerns about the negative impact of toothfish extraction.

Many papers have argued both ways about the importance of the fish as prey but there is little to no evidence to suggest that the toothfish are also valuable as a predator. This gap in the literature could be used to add weight to either side of the argument and further aid in the management of the fishery.

At this stage the ecosystem impacts of the fishery are greatly unknown and only impacts on specific components of the ecosystem have been investigated. The food web dynamics are complex and vary greatly dependant on the species and geographic location. Quantifying this into a way that fisheries management can assess their impact would prove beneficial and would aid in the "ecosystem based management approach".

Conclusions

The different conclusions and contradictions reported on should highlight the complexity of the Southern Ocean and the how impacts in some areas may differ based on geographic location. I hypothesise that the same complexities that surround the impacts at differing geographic distributions should be assumed for toothfish and their life histories at different locations, and therefor, fisheries management needs a precautionary approach so that impacts to the ecosystem are not dismissed or overlooked by encompassing the toothfish fishery as one management unit.

I question if hypothetical information is strong enough evidence to base a fishery on. Although these hypotheses are far from being disproven, I argue that a greater understanding, in regards to life histories, is needed before progressions and increased takes within the fishery are recommended. If we are to avoid a similar fate of those unsuccessful fisheries such as Orange Roughy and Atlantic cod, we should learn from the mistakes made that proved that a lack of understanding of fish biology has drastic negative effects.

Further research into juvenile toothfish survival rates, juvenile distributions, and geographic and water circulation influences should be carried out to help solidify knowledge and fill gaps around spawning complexities, spawning success, and egg fertilization. With this information more accurate models could estimate true fecundity and total biomass each season reducing the risk of population decline and in turn the effect on the ecosystem.

Further studies should also be carried out investigating the toothfish's role as a key predator in the ecosystem. Food web dynamics are fragile and trophic cascades could prove detrimental in a specialised ecosystem such as the Southern Ocean. These problems could be avoided, simply by defining the linkages and trophic interactions and weighting their importance within the Antarctic ecosystem.

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