Driven by speculation, not by impact – the effects of plastic on fish species

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Plastic products have facilitated the daily lives of an exponentially increasing world population for over 70 years, whilst inadvertently creating one of the most topical environmental issues of the 21st Century: the plastic pollution crisis. Since the mid-20th Century, plastic production has expanded continuously to global production levels of over 350 million tons in 2018 (Thompson et al. 2009; Plastics Europe, 2019). Articles surrounding the presence and impacts of plastic pollution on aquatic animals including fish species have become a regular occurrence on media platforms (Kramm et al. 2018) and scientific publications (Henderson & Green, 2020); however, while iconic pictures of individual fish and other taxa with variously attached or ingested plastics might make headlines, they do not of themselves prove impacts, absolute or relative, at population levels.

The public fixation with plastic pollution has both positive and negative effects. The production of plastic relies on finite fossil fuel reserves and both its creation and destruction adds increased CO_2 into the atmosphere (Mooney 2009). A combination of these factors and the persistence of non-biodegradable plastic has led to a general consensus that plastic is bad for the environment. Reducing the daily use of plastic is certainly a positive outcome to be taken from this latest environmental fixation (Schnurr et al. 2018). While the effects of plastic pollution on marine species are ambiguous, this issue now ranks among the heavyweights of environmental and marine issues such as climate change, the spread of invasive species, and overfishing (Stafford & Jones, 2019). As a consequence, the aforementioned urgent crises are being pushed further down the priority list in public perception; for example, a particular study showed how people continually rank pollution (including plastic) ahead of fishing, habitat alteration, and climate change in terms of the greatest threats to global oceans (Lotze et al. 2018). Although plastic pollution is now seen as a major threat to biodiversity (Deudero & Alomar, 2015), the direct effects of plastic products on fish species and seafood are disputed in the scientific literature (e.g. Ašmonaitė et al. 2018; Jovanovich et al. 2018).

We consistently show more sympathy for larger charismatic marine species (e.g. Barney et al. 2005). The death of a juvenile Whale Shark *Rhincodon typus* (Smith 1828) in the Philippines spurred global media attention in August 2018 as plastic waste was found to have blocked the gills which led to the animal's death. Corpses of charismatic species killed as a result of human sourced waste can spur rapid change (Eagle et al. 2016): fast forward a few months and we begin to feel better, now using 'bioplastic' cutlery and coffee cups. However, gillnet bycatch still kills up to 20 *R. typus* annually in Karachi harbour fisheries despite public effort to reduce single-use plastic (Moazzam & Nawaz, 2014). Additionally, replacing single-use plastic products with natural bio-benign alternatives still adds debris into the environment, much of which has at best questionable "biodegradable" potential (Godfrey, 2019).

Although interaction with plastic can have a number of effects on marine species, entanglement is the most documented and notable direct effect plastic has on fishes from observations in the wild (Derraik, 2002). 'Ghost fishing', where lost or discarded fishing nets continue to snare, can have major implications on fishes and a knock-on effect on other benthic species as a result; however, population level effects remain unknown (Kaiser et al. 1996). One study showed that ghost fishing nets can operate for over 140 days and can kill up to 450 fish per net after being discarded (Nakashima & Matsuoka, 2004). Additionally, it is estimated that 10% of annual marine debris is attributed to lost or discarded fishing gear (~64,000 tons; Macfadyen et al. 2009). Although fishing gear is generally made from synthetic polymers, is this an issue with fishing practice, rather than a direct impact of plastic production?

The plethora of scientific literature focussing on the impacts of plastic pollution on fishes, both marine and freshwater, is dominated by studies of 'microplastics', a term that was coined over 15 years ago to describe synthetic polymer fragments < 5 mm in length (Thompson et al. 2004). In terms of fish species, microplastic ingestion has been found in all habitats: from deep-sea (Zhu et al. 2019), pelagic systems (Barboza et al. 2019), freshwater (Roch et al. 2019), and intertidal systems (Ahrendt et al. 2019). Microplastic ingestion has also been noted in juvenile fish (Steer et al. 2017). In essence, the ubiquity of microplastic pollution is now fully established; however, the impact on individuals, communities, and populations of fish in the wild is still uncertain and undoubtedly case dependant (see Cunningham & Sigwart, 2019).

The fragmentation of macro plastic objects (> 5 mm) under UV and wave exposure is a common pathway for microplastics to enter marine and freshwater systems (Thompson et al. 2004). Severe and varied impacts have been correlated to high microplastics exposure in numerous laboratory studies (Cunningham & Sigwart, 2019). Similar to the ocean acidification research from the early 2000s (McElhany, 2017), many of these studies imposed unrealistically severe conditions, with plastics exceeding 1 million particles per tank. When you feed excessive amounts of plastic to fish, the results are largely negative. For example, at the lower end of excessive dosages, a significant reduction in fecundity was found in the Japanese Rice Fish *Oryzias melastigma* (McClelland 1839) when exposed to ~5000 microplastics/L (Wang et al. 2019). At the other end of the scale, Korean Rockfish *Sebastes schlegelii* (Hilgendorf 1880) showed adverse behavioural changes and high levels of gut blockage when exposed to 1,000,000 microplastics/L (Yin et al. 2018). These "plastic soup" studies raise more questions about scientific ethics than environmental impacts. Yet not all exposure studies are so extreme, and many more realistic studies exist within the literature; however, environmentally relevant dosages tend to show minimal impacts on individuals (Cunningham & Sigwart, 2019). The Gilt-head Bream *Sparus aurata* L. egested most of the consumed microplastics when exposed to lower, more environmentally relevant dosages and no immediate effects were noted (Jovanović et al. 2018). Similar studies using juvenile fish species found effects generally correlated to the dosage of plastic used in the experiments (Hamed et al. 2019). One study showed that microplastic particles induced no impacts on juvenile Palm Ruff *Seriolella violacea* (Guichenot 1848) and all consumed particles were egested in an average of seven days (Ory et al. 2018). As of yet, none of these studies translate into population or community level impacts, and even mortality or reduced fecundity of individuals might be compensated for by survival and enhanced reproduction of other individuals in female heavy populations (Ford et al. 2007).

Generally, the exposure studies using excessive dosages derive from an ecotoxicology background (Anbumani & Kakkar, 2018). The scientific motivation behind employing excessive plastic dosages during species exposure is often justified, as plastic production is increasing annually (Thompson et al. 2009). Although, these excessive studies have been criticised in the past (Troost et al. 2018), they are the only current medium we have for understanding the effects of plastic on fish species and also for determining potential tipping points for fish populations in the wild (Cunningham & Sigwart, 2019). Further research is needed to determine how environmental levels of plastics will affect fishes in the wild from the individual to population levels. Extensive effort has also been put into understanding how plastic pollution act as a vector for the transportation and bioaccumulation of Persistent Organic Pollutants (POPs; Bakir et al. 2014). Although the potential for bioaccumulation of POPs through microplastic ingestion has also been disputed in the literature (Lohmann, 2017), further research is needed to fully understand this potential impact of plastic on fish species.

Microplastic accumulation in the tissues of fish (Barboza et al. 2019) does leave seafood consumers open to microplastic exposure, but the impacts of these microscopic particles in the very low quantities they have been found (mean: 0.054 MP items/g tissue), are no more than the atmospheric microplastic particles we are exposed to daily (Catarino et al. 2018), or perhaps no more than chewing the end of your pen. Although it appears unlikely that microplastic ingestion in humans via fish and other seafood will have major effects on human health, this represents a significant research gap that needs to be investigated (Rainieri & Barranco, 2019).

Given the dearth of documented evidence on the direct impacts of plastic on fish communities and populations it is hard to draw comparisons with other, well documented environmental crises such as overfishing, aquatic alien species, and global warming. The effects of the Indo-Pacific Lionfish *Pterois volitans* L. and *P. miles* (Bennett 1828) alone on marine systems are extremely negative: considering their impact on native fish populations and their rapid expansion into new environments (Green et al. 2012). The long-term economic impacts of managing *Pterois sp.* populations globally are inestimable (Barbour et al. 2011), and more devastating when multiplied by the number of introduced fish species around the world. The variety of impacts associated with invasive fish species, such as hybridisation (Fukui et al. 2018), introduction of parasites (Spikmans et al. 2019), and outcompeting natives for prey (Camacho-Cervantes et al. 2019) have caused well documented negative impacts in wild populations.

Similarly, the effects of long-term unsustainable fishing practises have pushed certain fish species to the point of local extinction (Luiz & Edwards, 2011), with global extinction becoming an ever more realistic possibility. Today, over 90 species of European marine fishes are threatened by extinction due to overfishing (Nieto et al. 2017). The most vulnerable are elasmobranchs, a group of species that are vital for a structured and balanced ecosystem (Bornatowski et al. 2014). In addition, the IUCN Red List has determined that 37% of freshwater fishes in Europe are also threatened with extinction (Freyhof & Brooks, 2017). In the Northwest Atlantic alone, ~68% of fish stocks have been fished to the point where they can no longer produce maximum sustainable yields (Froese et al. 2019). The impact of overfishing on a population level has been highlighted (Collie et al. 2017); whereas, with plastic ingestion, we can currently only speculate about the impact on populations at this stage of the research area.

Additional, indirect anthropogenic impacts such as rising ocean temperatures are expected to reduce annual fish catches by 3 million metric tonnes per 1°C of warming (Cheung et al. 2016). Global warming is partly to blame for the collapse of the Atlantic cod *Gadus morhua* L. fishery, where excessive fishing effort drove a severe decline in stocks, yet increased temperature is now impeding any chance of recovery (Pershing et al. 2015). It is also believed that anthropogenic climate change is increasing the severity of warming events such as El Niño and La Niña in the Pacific, leading to a decrease in primary production at the equatorial Pacific and subsequent fluctuations in the recruitment of commercially important fishes (Brander et al. 2010). The associated impacts of invasive species, overfishing, and global warming on fish have all been highlighted extensively in wild populations: something we cannot say yet about plastic pollution.

Studying the impact of microplastics on fishery species has led us to believe that although issues may arise from the increased production of plastic in years to come, the effects are not as immediately harmful at the population level as global warming, overfishing, and invasive species. Global fish populations have been at risk for decades, and with increased warming, invasive species and overfishing, we may push them over the edge, regardless of plastic pollution. The impacts on fish populations are likely to be exacerbated by the synergistic effect of each of these stressors with the addition of plastic pollution also; and as a result, further research is needed to fully understand the effects of (micro)plastic on fish from the individual to populations.

Figure caption

Images of animals entangled in plastic pollution can spur rapid change towards reducing single-use plastics, but population level issues like overfishing, invasive species, and global warming still remain. Photo credit: Nopadol Uengbunchoo.

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