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DEPREDATION OF TUNAS AND TUNA-LIKE SPECIES BY MARINE MAMMALS: ECONOMIC IMPACTS OF A HUMAN-WILDLIFE INTERACTION.

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SUMMARY

Depredation, i.e. the partial or complete removal of caught fish from fishing gear by marine mammals, is attracting more and more attention from fisheries managers and society in general due to the growing concerns about the conservation of marine mammals' populations and Human-Wildlife interactions in general. This short background paper presents the key issues at stake for the Tuna fisheries and, in particular, the potential economic impacts, both for the fishing industry and for the society. While fishing vessels endure directly some costs (losses in production and gear damages), other costs can occur to implement unavoidable mitigation strategies. On the other hand, the depredation phenomenon can facilitate the feeding patterns of marine mammals and thus contribute to their well-being. As such, depredation could be seen as a phenomenon generating a positive externality, which might allow for compensation, as it is the case in several land activities. In addition to presenting the ecological and socio-economic impacts of depredation, the paper suggests that several integrated modelling approaches can be appropriately developed to capture the phenomenon.

RÉSUMÉ

La déprédation, c'est-à-dire la ponction partielle ou complète des poissons capturés des engins de pêche par des mammifères marins, attire de plus en plus l'attention des gestionnaires des pêcheries et de la société en général en raison des préoccupations croissantes concernant la conservation des populations de mammifères marins et les interactions entre l'homme et la faune en général. Ce bref document de référence présente les principaux enjeux des pêcheries thonières et, en particulier, les impacts économiques potentiels, tant pour l'industrie de la pêche que pour la société. Si les navires de pêche supportent directement certains coûts (pertes de production et dommages aux engins), d'autres coûts peuvent être engendrés par la mise en œuvre de stratégies d'atténuation inévitables. D'autre part, le phénomène de déprédation peut faciliter les schémas alimentaires des mammifères marins et contribuer ainsi à leur bien-être. Ainsi, la déprédation pourrait être considérée comme un phénomène générant une externalité positive, qui pourrait permettre une compensation, comme c'est le cas de plusieurs activités terrestres. Outre la présentation des impacts écologiques et socio-économiques de la déprédation, le document suggère que plusieurs approches de modélisation intégrées peuvent être développées de manière appropriée pour capturer le phénomène

RESUMEN

La depredación, es decir, la retirada parcial o total de los peces capturados de los artes de pesca por parte de los mamíferos marinos, está atrayendo cada vez más la atención de los gestores pesqueros y de la sociedad en general debido a la creciente preocupación por la conservación de las poblaciones de mamíferos marinos y por las interacciones entre el hombre y la vida salvaje en general. Este breve documento de referencia presenta las principales cuestiones que están en juego en la pesca de túnidos y, en particular, las posibles repercusiones económicas, tanto para la industria pesquera como para la sociedad. Mientras que los buques pesqueros soportan directamente algunos costes (pérdidas en la producción y daños en los artes de pesca), pueden producirse otros costes para aplicar estrategias de mitigación inevitables. Por otra parte, el fenómeno de la depredación puede facilitar las pautas de

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alimentación de los mamíferos marinos y contribuir así a su bienestar. De este modo, la depredación podría considerarse un fenómeno que genera una externalidad positiva, lo que podría permitir una compensación, como ocurre en varias actividades relacionadas con la tierra. Además de presentar las repercusiones ecológicas y socioeconómicas de la depredación, el documento sugiere que se pueden desarrollar adecuadamente varios enfoques de modelación integrados para captar el fenómeno

KEYWORDS

Economic Analysis; Economic Models; Tuna; Marine Mammals; Ecosystems

Introduction:

In the context of increasing knowledge about marine resources and growing concerns about sustainability issues, human-marine wildlife interactions are of growing interest to key stakeholders, particularly as these interactions most often involved multiples jurisdictions (Bellanger *et al.*, 2020). Human-marine wildlife interactions can usually imply hazard collisions (Sèbe, Nassiri and Pindleton, 2021), trophic competition[4] (Flaaten and Stollery, 1996), accidental bycatches, but also depredation. Depredation can be defined in the following ways (especially when considering the fisheries sector, although the phenomenon can also be observed inland, e.g. with wolf interacting with farming activities):

- *Collins dictionary: "*The depredations of a person, animal, or force are their harmful actions, which usually involve taking or damaging something. The act or an instance of plundering; robbery; pillage".
- *Peterson et al., 2015:* "animal stealing or damaging fish caught on fishing gear".
- *Romanov et al. 2013*: "the partial or complete removal of hooked fish or bait from fishing gear…" by predators such as cetaceans, sharks, bonefish, birds, squids, crustaceans and others" distinguishing it from predation, i.e. "the taking of free swimming fish (or other organisms)…"
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As for the seafood sector, Tixier *et al.* (2020) reported that depredation was observed in 214 fisheries worldwide between 1979 and 2019, although Japanese longliners made the first observations of this type of interaction at the beginning of the XXth century. Among the 68 predator species identified in Tixiers *et al*.'s paper, 20 are from the odontocete family, including, among others, killer whales (*Orcinus Orca*), false killer whales (*Pseudorca Crassidens*) or long-finned pilot whales (*Globicephala macrorhyncus*), which can all be involved in bycatch and depredation phenomena associate with tuna fisheries.
The paper first presents some cases of depredation involving tuna species. The second section describes the ecological and economic dimensions of depredation, while the third section attempts to identify the tools and data needed to fully understand and mitigate the depredation phenomenon.

1. Some example of depredation of tuna and tuna-like species across the world.

According to Fader *et al.* (2021), interactions with marine mammals are more significant in the case of pelagic longline fisheries than demersal ones, with pelagic longlines targeting wide-ranging pelagic species such as tunas (*Thunnus spp.*), swordfish (*Xiphias gladius*) and dolphinfish (*Coryphaenus hippurus*). In their paper, they focus on two pelagic longline fisheries in the United States that are subject to depredation and bycatch by odontocete depredators: the Hawai'i deep-set longline fishery, which is depredated primarily by false killer whales (*Pseudorca crassidens*), and the Atlantic pelagic longline fishery depredated primarily by short-finned pilot whales (*Globicephala macrorhynchus*).

In contrast with Atlantic tuna fisheries, several studies have specifically looked at the issue of depredation in the Indian Ocean pelagic longline fishery, covering the depredation of tuna species (bigeye tuna - *Thunnus obesus*, yellowfin tuna - *Thunnus alalunga*, albacore tuna - *Thunnus albacares*) and swordfish (*Xiphias gladius*) by sharks (blue shark - *Prionace glauca;* silvertip shark - *Carchahrinus albimarginatus*; or silky shark - *Carcharinus falciformis*) and odontocetes (long-finned pilot whales - *Globicephala macrorhyncus*; and false killer whale - *Pseudorca crassidens*). While depredation in these fisheries occurs more often in the case of shark, the damages are reported to be more significant in the case of odontocete.

[4] I.e. fishing vessels and marine mammals or birds competing for the same prey.

In the Mediterranean Sea, several studies were conducted about the depredation of Bluefin Tuna **(***Thunnus thynnus)* by killer whales in the Strait of Gibraltar (Moroccan and Spanish fleets) (Idrissi *et al.*, 2013; Abid *et al.* 2017). As populations of long-finned pilot whales are also observed in the Mediterranean Sea, at least in the Western basin (http://www.associaciocetacea.org/en/conservation/mediterranean-species/cetaceans/long-finned-pilot-whale/), depredation of tuna is also likely to occur (see also Werner *et al.*, 2015). Anecdotal information from a French tuna Producer Organisation seems to confirm that depredation of Bluefin Tuna is still occurring around Gibraltar (long-finned pilot whales and killer whales), although the phenomenon in the Gulf of Lions is less frequent and involves mainly sharks.

2. Ecological and the economic dimensions of depredation

2.1. *Ecological considerations*

Depredation is a case of interaction between human activities and marine mammals. As such, various negative and positive effects on the marine mammal populations can be listed:

i. According to Werner *et al*. (2015), longline incidental catch is considered to be a threat to several species, such as false killer whales in the Hawaiian Islands and Risso's dolphin and pilot whales in the Northwest Atlantic. Although longline fishing usually is less impacting than other fishing gears (e.g. gillnets), many individuals might suffer mortality and serious injury from the interactions. According to Fader *et al.* (2021), a risk of mortality can occur because of either hooking or entanglement in fishing gear or retaliation from fishermen. In the same line, Tixier *et al.* (2020) indicate that 73% of the predators involved in depredation were subject to either bycatch and /or retaliatory killing.

ii. Depredation is changing the foraging patterns of marine mammals, reducing the efforts needed to obtain their food. Depredation can thus have some positive effects on the intrinsic growth rate of the species involved.

iii. Marine mammals can compete with tuna during the foraging process, as they are eating the same species, such as fish and cephalopods (for juvenile tuna) and pelagic species (for adults).

2.2. Economic considerations

2.2.1. For the fishing industry

The fishing companies are viewing the depredation phenomenon as a cost for various reasons:

- Fishers are primarily concerned by the loss of valuable target catches, notwithstanding any other ethical issues (Werner *et al.;* 2015).
- There is a potential for target species to avoid taking baited hooks in the presence of predators (Tixier *et al*., 2020).
- Damages to gears.
- Additional gears and/or bait required to reach the quota.
- Additional time to clean and fix the gears, to avoid interactions, etc.

Some estimates have been made for tuna fisheries, although the full economic impact does not in general cover all the cost items[5]:

- USD 500,000 per year for the Tuna/swordfish Seychelles pelagic longline fishery (Tixier *et al*., 2020)
- USD 390,000 – 690,000 per year per vessel for the Tuna/swordfish Hawai'i pelagic longline fishery (Tixier *et al.*, 2020)
- As for the Bluefin Tuna Gibraltar fishery, the cost was estimated to average around EUR 1,400 per day in 2016 for the Ksar Sghir area, which represents around EUR 25,000 for the fishing season in the area.

[5] In the review made by Tixier *et al.* (2020), only 2 studies provided full socio-economic assessment of extra fuel consumption, additional work time and food expenditure, extra effort to compensate losses in catch and to implement mitigation strategies.

Considering these direct costs for the fishing companies, mitigations strategies can be envisaged, while also implying some additional costs:

- Deterrence:
    - Acoustic Deterrent Device (ADD), or pingers, and AHD (Acoustic Harassment Device) acoustically bother toothed whales and aim at preventing them from approaching the fishing gear to steal the fish and/or the bait and from being incidentally captured (Rabearisora *et al.*, 2012).
    - Non-lethal explosives / gunshots
- Behavioural avoidance
    - Targeting fishing activities with a low risk of interaction
    - Move-on practices (move from the fishing zone when the interaction is identified or anticipated), and associated fuel and personal costs.
- Gear modification

2.2.2. For the society

In the case of depredation by marine mammals, which are among the most protected species, some benefits can be generated as depredation can facilitate the foraging behaviour of the animals and increase their growth[6]. The stocks of marine mammals are thus expected to grow, which is a direct objective of conservation policies. In the same line, it also means that the trophic competition with tuna populations will be modified at the benefits of the marine mammals' population.

If these types of benefits can be identified, then it can be considered that the depredated activity generate positive externalities, which can be a basis for compensation schemes, as it is the case for depredation activities observed inland (e.g. in the case of depredation of livestock by wolves or bears in several countries; depredation of carps by cormorants in Eastern Europe Natura 2000 zones).

3. Tools and data needed to fully understand and mitigate the depredation phenomenon.

As indicated in Tixier *et al.* (2020), several anthropogenic and environmental factors can drive the occurrence and the scale of depredation. And a first necessary step to capture the full impacts of depredation is to improve the monitoring of the phenomenon. In some fisheries, such as the Patagonian toothfish (*Dissostichus eleginoides*) demersal longline fishery, the interactions with both Sperm whales and Killer whales are highly monitored and reported. And estimates of the volume of depredated fishes are made by scientists (*Museum National d'Histoire Naturel*). In the case of top predators such as tunas and swordfish, estimates might be easier to obtain, as, in general, the whole fish is not removed from the longline.

Taking as an example the analyses currently developed as part of the ANR research project Orcadepred, the following areas of investigation can be identified:

3.1. Analysis of Ecosystem impacts

The development of depredation by marine mammals is likely to modify the equilibrium of the ecosystem, as the population of depredated species might be strongly affected. Taking as an example the analyses currently developed as part of the ANR research project Orcadepred, ecosystem models (Ecopath / Ecotroph / Ecosim or any other trophic models) can be used to capture the full effects of depredation of the other components of the ecosystem. Several researches were indeed performed, in order to investigate the best way to include the depredation phenomenon in already existing ecosystem-based models. The results are summarised in the paper by Clavareau *et al.* (2020), entitled "*Comparison of approaches for incorporating depredation on fisheries catches into Ecopath*". The paper for instance assessed how three alternative model structures can account for depredation effects on fishery catches, predator and non-commercial prey populations, as well as target fish stocks. While none adequately addressing all facets of depredation, the alternative models can to some extent capture how depredation can lead to increased fishing pressure on stocks.

[6] Although natural predation of tunas by marine mammals may happen for juveniles and young tunas, this is more uncommon when tunas reach an adult age.

3.2. *Analysis of the economic impacts*

3.2.1. *Changes in economic values*

As the tuna markets are highly globalised, the price effect of depredation[7] is likely to be limited. However, in the case of specific niche markets, such as Bluefin tuna, the impact might be higher, especially if the depredation phenomenon is increasing in the future.

Conversely, the impact on some costs items, e.g. the fuel consumption, could be easily monitored if the information about a change in fishing patterns due to depredation was identified. The same could occur for working time and gear costs (extra number of gears or repair and maintenance operations).

Another approach could be to start from the cost items reported in account books and to investigate whether some statistical relationships with the occurrence of depredation could be observed.

3.2.2. *Development of a bioeconomic tool*

In complement of the ecosystemic analyses, a bioeconomic model exploring the effect of depredation on selected fishing fleets is currently under development in the AMURE research lab, with a first application to the French toothfish fishery in the southern Indian Ocean, around Kerguelen and Crozet islands. This toothfish fishery is operated by seven French longliners (on average 66 metres) and is suffering from the depredation by Killer Whales and Sperm Whales (*Physeter macrocephalus*).

The model follows the ideas develop by the few research papers focusing on the economic dimension of depredation since the seminal publication by Flaaten (see for example Flaaten and Stollery, 1996). The model is developed under R and is specifically designed to be generic and to allow data-poor situations. At this stage, the model structure is composed of five main modules:

- Module “Resource”: The model can accommodate single and multispecies situations to describe the resource(s) targeted by the fishing vessels. Surplus models or age-structured models can be parametrised for each stock, reflecting the available information, notably stock assessments.

- Module “Predator”: The stock(s) of predators can be fixed or can have a specific stock dynamic if sufficient information is available to model it. The key element of this module is the depredation ratio, which is the share of the depredation in the total catch. The depredation ratio can be a single figure or a vector allowing to adjust the ratio to the size of the fish depredated.

- Module “Fishing vessels” targeting the fish stocks. Several fleets can be included in the model, allowing to test management measures adapted to each fleet. The module describes the economic operations of the fishing fleets, allowing to project their operating profit. By default, the cost structure is extremely simple and is based on two costs: fixed annual costs and variable costs that are dependent on the nominal effort. Depending on data availability, the cost structure can be extended to include more items, such as fuel costs, crew wages and bait costs.

- Module “Activity”: this module links the nominal effort (in fishing days) to the effective effort used for the stock dynamics. It allows also splitting the total catch between the predators (depredation) and the fishers (retained catch).

- Module “Regulation and adaptation”: this module details the management measures potentially in place (quotas, seasonal closures…) as well as the mitigation measures fishers could implement to minimize the depredation (increased route time, additional costs: gear, bait, deterrents…).

This model is used to evaluate:

- the impact of an increasing depredation on the profitability of the fishing fleets, exploring the potential tipping points where fishing is not profitable anymore.

[7] I.e. the increase in price expected due to the decrease in quantity produced

- the impact of the management measures in place on the fleet profit levels, but also the unintended consequence they may have when depredation ratios are high.

- the economic impact of the mitigation measures potentially implemented by skippers and vessel owners.

3.3. Integrated approaches and trade-off analyses

In addition to ecosystem and economic impact analyses, trade-off analyses can be conducted as part of an integrated approach. There is indeed a growing interest in tools for scientists to communicate about trade-offs, and especially to illustrate feasible range for management responses to “uncertainty” and “variability” (Rindorf et al., 2017).

Stochastic co-viability analysis (Baumgärtner and Quaas, 2009; De Lara *et al.*, 2015) has been proposed as an approach that can help dealing with multiple objectives under uncertainty. This approach is probabilistic, i.e. it takes into account the probability of a fishery system to satisfy multiple constraints at each point in time, based on indicators and viability thresholds of diverse nature. This approach does not aim at identifying an “optimal” management solution (Doyen *et al*., 2019), but rather is related to “satisficing” desired objectives (Krawczyk and Kim, 2009). It aims to ensure a minimum acceptable level for various objectives. A distinct feature of viability analysis is that it does not require objective weightings. It is thus an alternative to traditional multi-criteria evaluation approaches (such as Analytic Hierarchy Process, Weighted Sum Models or Multi-Attribute Utility Theory), and is increasingly applied in the fisheries management literature (Cury *et al.* ,2005; Cissé *et al*., 2013; Maynou, 2014; Thébaud *et al*., 2014; Gourguet *et al*., 2016; Doyen *et al*., 2017).

In the context of depredation, it is important to determine the extent to which depredation rates need to be reduced to guarantee the ecological and socio-economic viability of a marine socio-ecosystem subject to depredation. In the context of the ANR project Orcadepred, a stochastic co-viability framework is currently implemented on the French demersal longline fishery targeting Patagonian toothfish to assess the trade-offs between ecological, economic and social indicators under artificial depredation rate scenarios.

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