The interactive effects of human activities, stress and aggression on disruptive behaviour in orcas (*Orcinus orca*)

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Abstract

In 2020, the Iberian orca (*Orcinus orca)* subpopulation started ramming boats, called ‘disruptive behaviour’, and since then this behaviour has started to spread among the subpopulation. This behaviour consists of their bodies colliding with the rudder of almost exclusively sailboats. A combination of different factors could have led to the rise of this behaviour, however, the decline of their main prey, the Atlantic bluefin tuna, could be seen as a trigger. Therefore, the downward spiral starts with human activities, mainly fisheries, as well as, tourism. Stress is caused by the vessels, and low prey abundance results in nutritional stress, which in turn causes an increase in the glucocorticoid hormones. These hormones in turn affect the behaviour of orcas, like aggression. Whereas stress is most prone in adult males, delivering and pregnant females, who have the highest levels of cortisol and corticosterone. Aggression is most expressed in males, but more research needs to be done on pregnant females. Additionally, the presence of vessels leads to a sensory overload leading to hyperaggression in some rare cases. Within captivity, only 1% of orca behaviour consists of ramming, but in case of the Iberian subpopulation, almost half of their interactions with vessels result in disruptive behaviour. This leads to a lot of damage to the boats but also negatively impacts the orcas who are already critically endangered. To eliminate this behaviour heatmaps created by orca sightings make the pods visual and marine protected areas could help. For further research, models containing the orca population and the tuna fisheries could see if the effect of removing fisheries from the model would benefit orcas.

Table of contents

Introduction

During the spring and summer months, a high number of Atlantic bluefin tuna return to the Mediterranean Sea to spawn (Esteban et al., 2014). This species is the main prey of the killer whale (*Orcinus orca*), causing three different populations of orcas to forage in the Strait of Gibraltar (Esteban et al., 2016). One of these populations is the Iberian subpopulation, living in the Strait of Gibraltar, who are critically endangered with only 39 individuals (Esteban et al., 2016). The high season of tourism overlaps with the peak of Atlantic bluefin tuna abundance, leading to interference with the orcas. People are willing to pay more and more for whale-watching tours, leading to vessels being closer and encountering orcas more frequently (Ouled-Cheikh et al., 2023). Besides tourism, fisheries are also intervening with orcas in the ways of captures, and collisions but also competition for the same food source (Díaz López et al., 2019). However, the orcas have discovered a method to benefit from fisheries through depredation, whereby they feed off the fish that has been captured by longlines (Athayde et al., 2023). All these human activities can lead to high amounts of stress in the orcas.

Orcas can endure different amounts of stress during their lifetime, but how is stress defined and how can it be measured? Stress is defined as prioritising a short-term threat benefitting their survival over making long-term choices like reproduction or growth and is based on energy expenditure (Busch and Hayward, 2009). Most new field research focuses on glucocorticoid hormones, corticosterone and/or cortisol depending on the study, for measuring stress levels in orcas (Busch and Hayward, 2009). When these levels are high this is noted as stress, however, glucocorticoid is always present in their system and is related to basic energy regulation (Busch and Hayward, 2009). Wild orcas suffer from acute stress, where there is a short response, however, captive orcas endure stress their whole lives leading to toxic stress (Haller, 2022). Toxic stress might lead to extreme behaviour and, as a result, can cause life-long health conditions (Haller, 2022).

Stress expresses itself in a variety of ways, but the most prevalent one is aggression, particularly in captive orcas (Marino and Frohoff, 2011). Glucocorticoid hormones have multiple mechanisms to affect the behaviour of animals, including aggression (Haller, 2022). Aggression is defined as competition with the aim of harm (Haller, 2022). In wild orcas, this is seen in the form of tooth rake marks, but with captive orcas, this can be more severe. So there is a link from the environment, in this case, human activities, leading to stress in orcas causing aggressive behaviour (Haller, 2022). However, since 2020 a new kind of aggressive behaviour called ‘disruptive ‘behaviour’ has arisen in the Iberian orca subpopulation, leading to the orcas jamming boats and even sinking them (Esteban et al., 2022). Researchers have suggested that this behaviour is mediated by the playfulness of the younger orcas (Zerbini et al., 2024), however, this behaviour might also be caused by human activities in orca-dense areas causing stress and thus disruptive behaviour. The aim of this study is to determine the underlying causes of this behaviour so that vessel owners can be informed in advance and prevent damage to their boats, besides, the Iberian orca subpopulation can be more intensively conserved. Other studies have not yet linked multiple factors (Fig.1) to get an insight to this sudden behaviour, but this review intends to fill that knowledge gap.

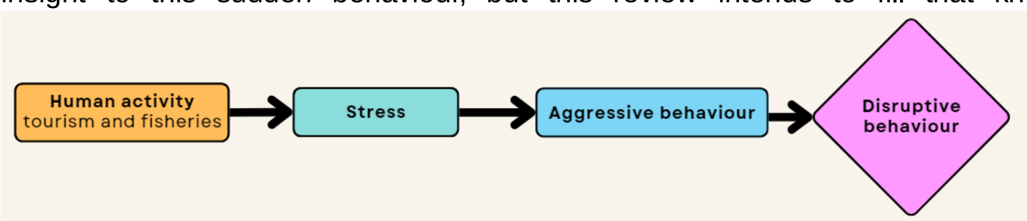

Fig. 1 Flowchart of the hypothesis

Thus, the following research question arises: How does stress induced by human activities affect disruptive behaviour in orcas?
In order to answer this question, a number of topics related to stress and behaviour in captive and wild orcas will be dissected by the use of sub-questions:

- "How does the behaviour of orcas change due to anthropogenic influences, tourism and fisheries?"
  Hypothesis: Human activities might influence the disruptive behaviour of orcas in association with stress.
- "Is disruptive behaviour mediated by hormonal pathways?"
  Hypothesis: Glucocorticoid levels are high when enduring high amounts of stress, this can be caused by anthropogenic influences which in turn mediate disruptive behaviour.
- "How does aggressive behaviour in orcas differ between age and sex?"
  Hypothesis: Disruptive behaviour might be more prone in adult males and less in females because they show more aggression.
- "What is disruptive behaviour and how can this be resolved?"
  Hypothesis: Disruptive behaviour might be resolved by reducing the Atlantic bluefin tuna quota and implementing marine protected areas.

This review paper uses data and articles from Web of Science, from researchers who looked into these topics, to answer these questions. There are more and more studies regarding the personalities and feelings of orcas (Úbeda et al., 2021), however, this review paper will not go into detail about that. Most papers will discuss wild orcas, however, the greatest harm caused by humans to orcas is not in the wild but rather as a result of our entrapment in aquariums and zoos. There are approximately 60 orcas worldwide living in captivity, some are born and raised others are robbed of their freedom (Marino et al., 2020). These animals endure a lot of stress and their physical needs are not met in their concrete tanks (Marino et al., 2020). Nonetheless, captive orcas can be studied more extensively than wild orcas and therefore are used in this paper to understand the disruptive behaviour better.

Study species

The Iberian killer whale is a subpopulation living mainly in the Strait of Gibraltar, but can also be seen around the Iberian peninsula, following the coast of Spain, Portugal, Gibraltar and France (Esteban and Foote, 2019). The subpopulation has derived from the northeast Atlantic population and has now its own mitochondrial DNA, stable isotope ratios and contaminant loads (Esteban et al., 2016). Since 2006, have they been listed on the IUCN red list as critically endangered, because this subpopulation only consists of 39 individuals. Their main prey is the critically endangered Atlantic bluefin tuna, but they can also feed on other fish as they are opportunistic feeders (Esteban and Foote, 2019). Orcas can use echolocation to hunt fish, hunt as a group or depredate, feeding on the fish that is caught by long-line fisheries (Esteban and Foote, 2019). Besides hunting, are swimming, resting and diving all natural behaviours and of course aggressive behaviour in the form of pushing, tail kicking, biting and raking (Sánchez–Hernández et al., 2019). Since 2020, a new kind of behaviour called 'disruptive behaviour' has arisen in the Iberian orcas, this entails the orca colliding with the rudder of almost exclusively sailboats (Zerbini et al., 2024). Beforehand, only 1% of the behaviour expressed in captive orcas was ramming (Sánchez–Hernández et al., 2019), but now half of the interactions entail this behaviour (Díaz López and Methion, 2024).

Research Findings

In this part, all papers and publications found on Web of Sciences will be summarized to make conclusions about the behavioural differences of orcas regarding stress, captivity but also human impacts. Research studies on the topics of stress, aggression, captivity and boat interactions will be examined, including effects in association with age, sex and season. Every sub-question will be answered in separate sections, to get a clear overview as answer to the research question.

Behavioural changes in orcas caused by humans, tourism and fisheries

Whale watching is an increasing tourism business, more and more boats try to get near whales or dolphins and tourists are willing to pay large amounts of money to get a glimpse of these marine mammals (Ouled-Cheikh et al., 2023). However, this also poses problems for these animals as they are disrupted in their lives. Therefore, in this section, behavioural changes in orcas caused by humans, tourism and fisheries will be examined by the answer to the question: How does the behaviour of orcas change due to anthropogenic influences, tourism and fisheries?

The number of whale-watching boats has significantly increased over the past years influencing the behaviour of orcas (Esteban and Foote, 2019). There is a significant negative effect on the behaviour of orcas compared with vessels in the southern resident killer whale around the area of San Juan islands (Holt et al., 2021; Lusseau et al., 2009; Williams et al., 2009). Holt et al. (2021) found that orcas would forage less if boats came within a 350 meter distance and they would spend more time travelling. There is a significant effect on female orcas and their forage behaviour when vessels are further than 350 meters, indicating that they would forage more efficiently when there is a bigger distance (Holt et al., 2021). When there is a high vessel abundance the noise can mask the fish detection, which makes it harder to forage (Lusseau et al., 2009). The whale-watching vessels in the Mediterranean follow the Royal Decree 1727/2007 which was put in place by the Spanish government allowing whale-watch vessels to come as close as 60 meters (Elejabeitia et al., 2013). When vessels come this close the sound must completely mask the echolocation of the orca, making it almost impossible for them to forage when they are watched. There are multiple studies performed on the effects of vessels on the behaviour of the southern resident killer whale but not yet on the Iberian killer whale. The short-term effects of habitat degradation, redistribution and in some cases mortality have been described (Notarbartolo di Sciara, 2016), but not behavioural changes and how this impacts the orcas' forage behaviour. Further research is required to gain a better understanding of how vessels affect the subpopulation of Iberian orcas.
Moreover, both sexes express themselves more when the vessels are nearby in ways of acoustic searches and intermediate dives (Holt et al., 2021; Lusseau et al., 2009). However, because female orcas forage less in the proximity of vessels, whale-watching is a bigger problem for female orcas than for male orcas. Therefore, it would be best if the desired pod could be identified before approaching to check the ratio of male to female orcas or whale-watching vessels could include cameras and sound systems to let the tourist observe the orcas from a further distance. These techniques would vessels allow to be at a greater distance than 350 meters and therefore disturb the natural behaviour of the orca less.

Furthermore, the presence of vessels not only leads to a change in forage behaviour and other forms of behaviour but also causes stress. This was studied by Ayres et al. (2012) who collected 154 faecal samples of southern resident killer whales in the Salish Sea during

2007, 2008 and 2009. These researchers did not find a significant effect of the presence of vessels on the stress levels in orcas. Additionally, whale-watching vessels did not significantly increase the cortisol levels of humpback whales in the Gulf of Alaska, which is a measure of stress (Teerlink et al., 2018). This might indicate that the presence of all the whale-watching vessels does not have a significant effect on the disruptive behaviour of the orcas. However, because measuring the glucocorticoid hormones in wild marine mammals is such a new field of study, more research needs to be done. The use of faecal hormonal metabolite samples to measure stress from anthropogenic influences is increasing (Yehle, 2022), but mostly humpback whales are the subject of these studies. To reject the hypothesis of anthropogenic effects based on two studies is not scientifically correct.
On the other hand, Ayres et al. (2012) also looked into nutritional stress occurring in southern resident killer whales which did have a significant effect. The glucocorticoid levels within orcas rose when the chinook salmon declined, indicating that prey availability has a big impact on the stress they endure. Prey availability correlated with vessel abundance had a significant effect on the stress levels of the killer whales. Therefore, the problem might not lay within tourism vessels, but fisheries including their competition with the same food source as the presence of their vessels. The rise of nutritional stress within the population might also explain the behaviour of depredation, where orcas feed on the fish caught by longlines.

Worldwide fisheries are facing an increasing problem of fish caught on longline gear being damaged or removed by whales, which is known as depredation (Peterson et al., 2013). Multiple studies are indicating that the number of killer whales depredating on fisheries is increasing and this behaviour is spreading among multiple orca populations (Amelot et al., 2022; Belonovich et al., 2021; Peterson et al., 2013). Fisheries lead to the rise of nutritional stress, but by means of depredation, this stress is lowered. Esteban et al. (2016) described that the Iberian orca subpopulation can make good use of depredation because otherwise most of the Atlantic bluefin tuna would swim too deep and would be unavailable for them. Long-line fisheries bring the tuna towards the surface making them accessible for the orcas to feed on. Therefore, it is difficult to say whether fisheries are the cause of the increased stress in the orcas and if they would benefit from less fishing activities. Further studies on the effects of fisheries on nutritional stress in Iberian killer whales could provide better insights into how varying levels of fishing activities influence disruptive behaviour.

Stress

As mentioned in the introduction, most new field research focuses on glucocorticoid hormones, corticosterone and/or cortisol, for measuring stress levels in orcas (Busch and Hayward, 2009). Stress levels in orcas are in correlation with fisheries, but is this also linked to disruptive behaviour? To examine how stress levels affect orcas, the following question will be answered: Is disruptive behaviour mediated by hormonal pathways?

To test glucocorticoid hormones faecal samples and in captivity serum samples can be taken, to measure the fluctuation. Within captivity 14 to 30 orcas from multiple SeaWorld locations in America showed significant amounts of glucocorticoid hormones indicating stress (O’Brien et al., 2017; Steinman and Robeck, 2021). The circadian rhythm has an influence on the glucocorticoid hormones in particular the morning has a significant effect on stress levels (Steinman and Robeck, 2021). Corticosterone increases significantly with age for both male and female orcas, but for cortisol, there is only a significant increase in males (Steinman and Robeck, 2021). Indicating that it is best for fisheries to fish later in the day as the stress hormones are highest in the morning. With less vessel interference in the morning, the disruptive behaviour might be reduced. Identifying the pod before approaching would be

beneficial as females have lowered cortisol levels than male orcas, therefore approaching a female-biased pod will make the chances of disruptive behaviour smaller.
For wild marine mammals, researchers mostly only study faecal samples, however, some studies do capture the animals to get serum samples (Norman et al., 2012). Nevertheless, this could cause even more stress for the animals and give a biased result. Glucocorticoid hormones in southern and northern resident killer whales were highest when stressed and pregnant (Yehle, 2022). Studies on the stress levels of marine mammals, including orcas, are extremely scarce, and there is none on Iberian orcas specifically. More research could improve our understanding of the connection between disruptive behaviour and stress.

Thus, approaching female-biased pods is generally better than approaching male-biased pods this changes when they are pregnant. Female killer whales have increased glucocorticoid hormones during parturition and pregnancy (Robeck et al 2017; Steinman & Robeck 2021). Thus, it would be advised that a database detailing the estrous cycle of female killer whales and their pregnancies be put into place for all vessels close to the orca subpopulation. Additionally, Robeck et al. (2017) also found that cortisol levels significantly increase during fall. This is aligned with the peak of nutritional stress, due to the decrease of Atlantic bluefin tuna. In order to reduce human-orca encounters and, consequently, the likelihood of boat rammings, it would be preferable to limit vessel contact with orcas during fall.

Besides sex and season, age also plays a major role in the amount of glucocorticoid hormones. O'Brien et al. (2017) concluded that glucocorticoid hormones are lowest in juveniles and highest in adults. All in all, adult male killer whales have the highest levels of glucocorticoid hormones and therefore seem to have the highest amount of stress. Further research could study which group causes the most harm during a boat attack. Namely, this could be adult male orcas, as well as, females during their pregnancy or parturition. If this group is identified, sightings of pods with this group as the main part could be passed on so these pods will be avoided. This information could be used by whale-watching companies, but also by sailors.

Aggressive behaviour

As was discussed previously, glucocorticoid hormones can be used as a way to identify stress, but they also influence behaviour in the way of aggression (Haller, 2022). Normally, it is difficult to quantify aggression in marine mammals because this behaviour is short-term and therefore difficult to observe. However, when orcas express aggressive behaviour within the pod or with objects tooth rake marks on the orcas' bodies will appear. Following wild orcas, photographing, videoing sightings and analysing these sessions will lead to an insight into the number of rake marks on their body and therefore the aggressive behaviour of the pod. In this section aggression in orcas will be reviewed by answering the following question: How does aggressive behaviour in orcas differ between age and sex?

Aggressive behaviour might vary with age and sex as well as between captive and wild animals, though captive animals tend to be the subject of more extensive research. A study by Marino et al. (2020) described different aggressive behaviours in captive killer whales in relation to stress. Firstly, captive orcas display hyper-aggressive behaviour even though in wild orcas this behaviour is also sometimes observed, this occurs more frequently in captive individuals. Nonetheless, this data can be biased towards captive orcas. Hyper-aggressive behaviour in captive orcas can be displayed as ramming against the wall of the tank or in some rare case the trainer gets killed. There are a few cases where hyperaggression in wild orcas led to harming a conspecific (Visser, 1998). However, in most cases, wild orcas disperse and therefore demonstrate avoidance behaviour when showing hyperaggression. So when orcas show hyper-aggressive behaviour and there are too many vessels surrounding them they cannot exhibit avoidance behaviour, which might cause them to show disruptive behaviour.

In addition, captive killer whales experience severe stress due to a lack of sensory input affecting their mental health (Marino et al., 2020). Nonetheless, wild orcas might get overstimulated by too much sensory input which can also cause stress and therefore aggression. During the summer months, there is a lot of activity in and on the water which might lead to a sensory overload of the orcas. There is not yet a lot of research done on the effects of noise pollution on aggressive behaviour in marine mammals. Further research could focus on the behavioural differences of months with less noise pollution and months which are loud. Besides noise pollution, stress also has a significant effect on aggressive behaviour, this might even be linked to nutritional stress.

As mentioned before, in wild orcas aggression is seen in the form of tooth rake marks, which are skin damage and if not healed properly can form a scar. Grimes et al. (2022) monitored a group of southern resident killer whales consisting of approximately 75 individuals for over 40 years. The study concluded, as expected, that males have significantly higher rake density than female orcas. However, rake marks between ages differ between sexes, calf females have the highest density whereas this is the case for calf males and juveniles. The study also looked at the salmon abundance in correlation with the rake marks which led to a significant relationship. The rake density is highest during periods of maximum salmon abundance for both sexes. This can be explained by increased social interactions when food abundance is high, leading to more playful and even aggressive behaviour. Conversely, nutritional stress is highest when prey availability is low, which can be expressed as aggressive behaviour. However, maybe the glucocorticoid hormones caused by nutritional stress may be expressed differently, perhaps in the form of depredation rather than aggression.

Whereas with glucocorticoid hormone and stress the highest abundance was in adult males, delivering and pregnant females, aggression is more prone in the younger individuals (Grimes et al., 2022). Stress might be highest in adults, because they endured a lot during their lifetime, whereas with younger individuals glucocorticoid levels rather lead to aggression than stress. However, when looking at a study by Anderson et al. (2016) who describes the behaviour of captive orcas from SeaWorld. From 1964 till 2016 45% of the orcas have been involved in incidents caused by aggressive behaviour. These incidents were almost all caused by sexually mature males and females only 1 pre-puberty female and 2 puberty females were the other perpetrators. In these cases, stress and aggression are combined because captive orcas suffer from toxic stress. So, the rake marks from adult orcas originate from stress and real aggressive behaviour, whereas the rake marks from young individuals are probably the cause of playful behaviour which became a bit too aggressive.

This is also in agreement with a study by Robeck et al. (2019) who examined the northern resident killer whale of 2010 through 264 images and the transient killer whale of 2012 through 57 images. Rake marks significantly increase with age in males and males had a significantly higher density of rake marks compared to females. Since females have fewer rake marks than males it would be interesting to see if they express more aggressive behaviour when they are pregnant. Since females produce more glucocorticoids when they are pregnant and give birth, it is possible that this also affects aggression. The female orca does behave differently during the estrous cycle, in ways of social interactions with males (Horback, 2010). Further studies can focus on this behavioural change in pregnant females in captivity, this might not be possible to study in wild orcas.

Disruptive behaviour

Orcas typically display aggression by pushing, kicking their tails, and leaving rake tooth marks, but starting in 2020, the Iberian orca subpopulation has begun to ram boats. Scientists have described this type of behaviour as disruptive. This leads to the following question to be answered in this section: What is disruptive behaviour and how can this be resolved?

Sailors are increasingly scared of an attack from an orca on their boat, but the interactions keep on happening around the Iberian peninsula. Killer whales were observed and recorded by Esteban et al. (2022) around Portugal, Spain, France and the Strait of Gibraltar during 2020. A total of 49 interactions with vessels were observed consisting of 35 sailboats. In most cases, they attack the rudder of the boat causing great damage and sometimes even leading to the boat sinking (Fig. 2). Over the years from 2020 to 2023, almost half of the interactions of orcas with vessels is in a disruptive way (Díaz López and Methion, 2024). The behaviour of orcas is unaffected by whether boats stop or continue moving and the behaviour keeps spreading through the population via horizontal learning (Skinner, 1969). Orcas are highly social animals that learn new behaviours through horizontal learning, which involves mimicking and copying the actions of others.

Fig. 2 Orca ramming the rudder of a sailboat and the damage it can lead to (Grimmett, 2021; Rusch, 2023)

The best advice to resolve this behaviour would be to create marine protected areas where vessels may not enter, which is best for the sailors because their boat will not be damaged and best for the orcas because they will have more freedom. Using sightings of orcas, heatmaps can be made of which places are orca-dense and therefore need to be avoided while other areas sailors can use.

This behaviour also occurs in other animals mostly terrestrial mammals, for example in monkeys but also elephants. Monkeys started the behaviour mostly due to gaining more food availability by taking it from humans (Das, 2017). This is similar to the orcas which are impacted by nutritional stress due to the decline of Atlantic bluefin tuna. So the behaviour is not necessarily targeted at humans, but more evolved from expressing nutritional stress which indirectly impacts humans. Consequently, getting the Atlantic bluefin tuna population to the original numbers would decrease the stress affecting the orcas. This might reduce the disruptive behaviour and maybe over time eliminate it.
When looking at disruptive behaviour in elephants this is more correlated with the decline of their habitat leading them to be closer to villages and thus causing disruption (Thouless, 1994). Orcas are not directly subject to habitat destruction because they can roam the whole ocean. However, humans have an indirect impact on ocean acidification and the use of the ocean for fishing, trade and recreational purposes, leading to habitat fragmentation and destruction. Hence, marine protected areas could be the solution to give orcas more space

and room in their natural habitat for them to live. This might even lead to a bonus of presumably an increase in Atlantic bluefin tuna. There are already some marine protected areas (Blanco et al., 2020), but the Iberian peninsula, which follows the coast of Spain, Portugal, Gibraltar and France, is a really big area. If there were more marine protected areas, where the Iberian orca subpopulation could reside they would truly benefit from them.
The behaviour of the southern resident killer whale, which has been observed to harass and kill porpoises without eating them (Giles et al., 2024), comes closest to disruptive behaviour. This behaviour also spreads among the population and is seen as a practice for hunting and as playful behaviour (Giles et al., 2024). Nevertheless, this population is critically endangered, just like the Iberian Orcas, due to a decline in prey. Hence, this behaviour might have arisen the same as disruptive behaviour, due to the link of human activities leading to stress expressed as aggression causing disruptive behaviour.

Summary

The answer to the question: “How does stress induced by human activities affect disruptive behaviour in orcas?” is a complex pathway involving human activities, mainly fisheries, stress and aggression. Additionally, nutritional stress but also diet in general play a central role in the cause of disruptive behaviour. Disruptive behaviour is somewhat of a downward spiral which starts with the Atlantic bluefin tuna whose numbers have decreased for a long time and only since 2006 started the increase again (Bjørndal, 2023). Orcas gather for the return of their prey through the Strait of Gibraltar and then encounter a high abundance of tourism, fish and recreational vessels, causing them great amounts of stress. Especially fisheries who compete for the same food source have a significant impact on the orcas and the abundance of prey also leads to nutritional stress. These stress levels consist of glucocorticoid hormones and are the highest in adult males, delivering and pregnant females, as well as, in the morning and during fall. Glucocorticoid hormones in turn affect the behaviour of orcas in the way of aggression. Aggressive behaviour can be seen in all ages and sexes, but is most expressive in adult males, furthermore, in younger individuals, this is progressed from playful behaviour. Nonetheless, human activities can also instigate aggressive behaviour through sensory overload and high vessel abundance, which can lead to hyperaggression. Disruptive behaviour is in a sense aggressive behaviour only this involves ramming boats. Maybe the orcas want to have less nutritional stress and they think that by attacking vessels there will be more prey. This is a way to make it full circle because this behaviour only impacts the orcas negatively by harming themselves and does not lead to more prey. By implementing marine protected areas the orcas will benefit in numerous ways, namely no stress from vessels, therefore also eliminating hyperaggression and maybe even a rise in the Atlantic bluefin tuna population. Furthermore, heatmaps showing the Iberian orca subpopulation containing all information on recent sightings could benefit the sailors to not go through orca-dense areas.
All in all human activities mainly fisheries are linked to stress, these glucocorticoid hormones impact aggressive behaviour and this is mediated as disruptive behaviour. The main trigger for this cascade is nutritional stress coming from fisheries and the abundance of Atlantic bluefin tuna.

Future research

In the future researchers can focus on multiple aspects like the influence of fisheries, how the behaviour spreads among the subpopulation, but also long-term studies on this behaviour and mitigation strategies.

The influence of fisheries could maybe be studied in a controlled setting or scientists could model the effects of removing fisheries on the glucocorticoid levels of orcas. This can go both ways due to the orcas depredating on longlines for their prey and this behaviour costing them less energy instead of hunting, but it will probably remove nutritional stress by having more tuna available. Depredation leads to better survival for the individuals contributing but also leads to a higher death rate (Guinet et al., 2015). So again if the number of Atlantic bluefin tuna would further rise there would be no need to start with depredation, because there would be nutritional stress to begin with.

The disruptive behaviour spreads among the subpopulation through horizontal learning (Skinner, 1969), orcas are highly social animals, who learn through mimicking. How this precisely started is still unknown, also remarkably the time when COVID-19 hit the world was the first interaction. Notably, the vessels were less abundant during that time, which would lead to less stress and thus less aggressive behaviour. However, during the summer months the interactions increased significantly so that would follow the hypothesis (Esteban et al., 2022).

As for tracking this behaviour, it would be really interesting to see this behaviour evolve over time. The Iberian orca subpopulation has 9 identified individuals of the 39 orcas who express this behaviour, possibly more individuals will pick this up, however, there is also a chance that one day all orcas will stop. It would also be fascinating to see if other orca populations who cross paths with the Iberian subpopulation will start to show disruptive behaviour. By using sightings, recordings and notifications when interactions with vessels happen a clear overview can be made. This information can also be used for sailors to avoid future boat rammings.

Throughout this thesis, there are already some mitigation strategies mentioned like marine protected areas, but future research can focus on more than that. At first, due to the glucocorticoid hormones being highest during fall and in the morning, season and time restrictions can be implemented to reduce the attacks. In addition, the speed of vessels can be limited to maybe also reduce the stress and the sensory overload. Besides, a more costly experiment is adapting the boat to make it less attractive for the orcas to collide their bodies with the rudder. A cheaper option is the use of deterrent devices, for example, pingers are a useful tool for bottlenose dolphins (Leeney et al., 2007). At last, drones could be used to track the orcas without disturbing them, including collecting data on their behaviour. All these strategies can be studied by researchers to see the effectiveness of them all and know what is the best way to resolve this problem.

Conclusion

In conclusion, there might be a link between human activities, particularly fisheries, and stress in adult males, parturition and pregnant females. They have high levels of glucocorticoid hormone leading to aggressive behaviour, which mostly shows in males. This aggression can be expressed as disruptive behaviour due to nutritional stress and habitat destruction. More studies need to focus on the effects of whale-watching vessels and stress in marine mammals, besides, studies on aggression in pregnant orcas. The Iberian subpopulation is critically endangered and if this link can be understood they can be better protected and conserved. On the other hand, sailors will benefit if researchers know the cause of disruptive behaviour by the protection of their vessels.

Afterword

AI technologies were used in the beginning as a brainstorming tool, although later on AI was not used and it is not presented as my own work in this thesis.

Ever since the boat attacks started in 2020 I wanted to know more about why the orcas started with this behaviour. Marine biology intrigues me greatly, and animal behaviour, in particular, fascinates me. Being accepted to do the marine biology master's encouraged me even more to choose a topic within that field. I would have loved to read even more articles about this topic, but with the time given, I feel like I have enough understanding of the orcas to present this thesis.

I would like to thank Martje Birker-Wegter as my supervisor for all the feedback you gave me and for help structuring this thesis.

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