Vessels and their sounds reduce prey capture effort by endangered killer whales (*Orcinus orca*)

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ABSTRACT

There are vessels (boats and ships) throughout the marine environment. However, we don't understand vessel impacts on marine wildlife, particularly cetaceans, due to challenges of studying fully-aquatic species. To investigate vessel and acoustic (noise) effects on cetacean foraging behavior, we attached suction-cup sound and movement tags to endangered Southern Resident killer whales in their summer habitat while tracking location and noise of nearby vessels. We could tell when orcas dove to capture prey and found that the probability of success increased as salmon abundance increased, but decreased as vessel speed increased. When vessels emitted navigational sonar, whales made longer dives to capture prey and descended more slowly at the start of these dives. Finally, whales descended more quickly when noise levels were higher and vessel approaches were closer. These findings advance our understanding of vessel and sound impacts on marine wildlife and inform efforts to manage vessel impacts on endangered populations.

INTRODUCTION

Conserving wildlife and their ecosystems often depends on modifying harmful human activities. This requires understanding the needs of the wildlife, which is hard to do when they live underwater. Vessel traffic is a problem for cetaceans (whales and dolphins) globally. Vessels sometimes run into whales, pollute the environment, disrupt activities, and introduce noise that hinders the cetacean's use of sound (Senigaglia et al. 2016; Lundin et al 2018; Erbe et al 2019; Schoeman et al. 2020).

Noise can cover up acoustic (sound) signals used during communication and foraging and affect the ability to capture enough food. Many vessels also emit high frequency sonar to aid navigation or fishing (e.g., depth sounders and fish finders) but we know little about how these noise signals affect cetaceans' use of sound, especially for those that depend on echolocation to find food.

We also don't know what it is about the vessels that creates the greatest risks for whales. But now, with the engineering of new bio-tracking technology, we can now measure what the whales do in response to the presence of boats, the noise they make, and what they are doing.

Here we investigate the effects of vessel sounds on endangered southern resident killer whales. These resident orcas hunt mainly salmon and especially Chinook salmon, which are also endangered. There is lots of vessel traffic from whale watching, commercial shipping, fishing, and recreation in their summer habitat in the Salish Sea. Previous studies reported changes in whale activity type, vocalizations, and diving patterns in response to vessels and noise (Williams et al. 2002, 2009; Holt et al. 2009, 2021; Lusseau et al. 2009; Noren et al. 2009). Reduced foraging is a commonly observed response to vessel disturbance, meaning less fish eaten. This can leave whales without enough calories to stay healthy. Most studies, however, base their inferences on what they could observe the whales doing at the surface only. Thanks to our new technology, we were able to also track the whales' behavior under water.

We used high-resolution tags, suction-cupped to the orcas. The tags tracked movement and speed and we observed for successful prey captures, which allowed us to test the effects of vessel quantity, speed, distance from whale, and the presence of depth sounder signal (the independent variables) on the probability of prey capture (the dependent variable).

Our findings increase understanding of how vessel noise negatively affects orca foraging success and provide data needed to inform decision makers on appropriate actions to take.

MATERIALS AND METHODS

We deployed digital acoustic recording tags (Dtags) on southern resident killer whales in the San Juan Islands and Gulf Islands of the Salish Sea in September 2010, 2012, 2014, and June 2011. This was during commercial whale watching season. Research permits from the National Marine Fisheries Service (US) and Department of Fisheries and Oceans (Canada) and approval from the NFSC's Institutional Animal Care and Use Committee gave us permission to attach Dtags to whales.

We put the tags on the whales with suction cups by standing in the bow of the research boat and placing the tag on the end of a long pole to reach the whale. We identified the whale using the photo-identification catalogues from the Center for Whale Research (Ford et al. 2000). The Dtag housed two hydrophones (underwater microphones), temperature, pressure, and accelerometer and magnetometer sensors (Johnson and Tyack 2003). We programmed the tags to release 1 hour before sunset, though some released earlier due to suction cup failure. We did the following after each Dtag was attached:

1. We followed the tagged whale and observed all vessels within 1.5 km of the tagged whale, including our research vessel.
2. We used gps, compass, and a range finder to track the location of the whale and each vessel (Giles 2014).
3. We recorded location at each surfacing and any indication of prey capture.
4. We collected prey remains when possible for further analysis.
5. We recorded each vessel's latitude and longitude position, vessel name and class (commercial whale watching, private, research, enforcement, etc) and estimated speed.
6. We scored vessel speed as 0 = stationary, shut down or idle, 1 = slow (1-2 knots), 2 = medium (3-4 knots), 3 = fast (5-6 knots), 4 = very fast (7+ knots).
7. We determined whether the whale was exposed to boat sonar, such as a depth sounder or fish finder (Figure 1).
8. We downloaded and processed tag data using the Dtag Toolbox (www.soundtags.org) and MatLab.
9. We used math called statistical analysis to calculate the probability of successful prey capture in response to vessel noise level, speed, distance, and depth sounder signals.

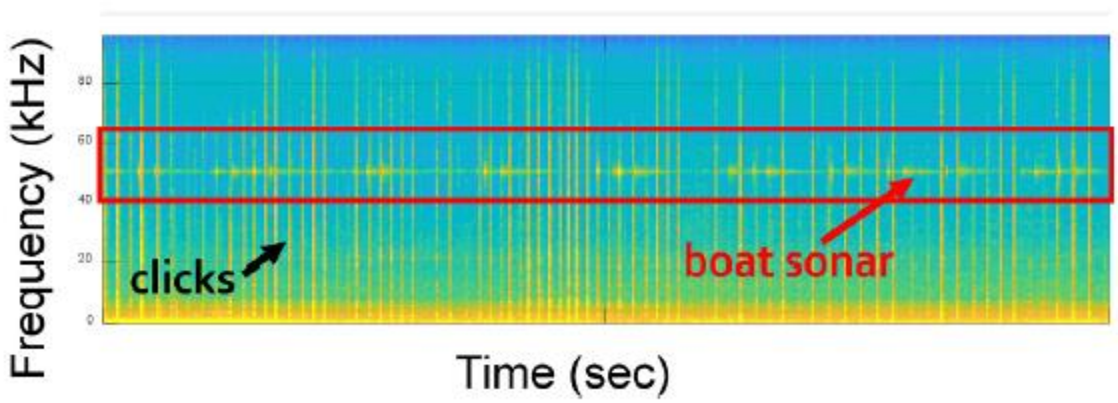

Fig. 1. Representative example of echolocation clicks of the tagged whale (black arrow) and 50 kHz navigational sonar emitted by boats (red arrow) recorded by the tag. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Note that each yellowish vertical line is an echolocation click. These cover a wide range of sound frequencies. The boat sonar (echosounder) sound frequency is right in the middle of the orcas' echolocation range, meaning they can potentially cover up (mask) the sound of the clicks sent out and returning to the whales.

RESULTS

We successfully attached tags and logged data for 17 whales (Table 1).

Table 1 Summary of tag deployments.

Year	Deployment	Whale ID	Sex	Tag duration (h)	No. dives ≥30 m
2010	oo10_257 m	L88	M	4.50	2
2010	oo10_261 m	L72	F	0.72	3
2010	oo10_264 m	L83	F	2.72	1
2010	oo10_265 m	K33	M	6.27	16
2010	oo10_267 m	J14	F	4.00	5
2010	oo10_268 m	L86	F	7.48	5
2010	oo10_270 m	L78	M	1.13	4
2012	oo12_250 m	L22	F	6.95	17
2012	oo12_251 m	K33	M	1.67	5
2012	oo12_261 m	L84	M	2.22	2
2012	oo12_266 m	L91	F	2.65	6
2012	oo12_266n	L47	F	0.78	1
2014	oo14_249 m	L113	F	7.17	13
2014	oo14_250 m	L89	M	8.88	11
2014	oo14_263 m	L85	M	6.38	7
2014	oo14_264 m	L91	F	0.83	4
2014	oo14_265 m	K35	M	4.77	13

We found that the probability of prey capture decreases the faster a vessel is travelling. We also found that the probability of prey capture increases when there are more salmon present and that overall, females capture less prey than males (Figure 1).

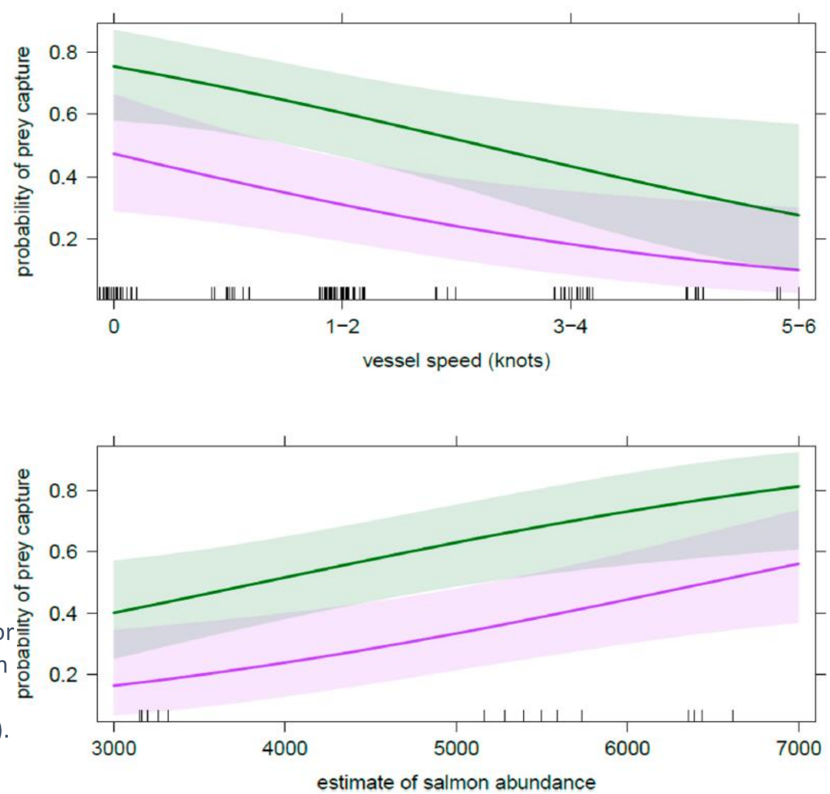

Figure 2 | Probability of prey capture for males (green) and females (purple) with increasing vessel speed (top) and increasing numbers of salmon (bottom).

We found that the whales dove for longer periods to catch fish when exposed to vessel sonar (echosounder), that females dove for shorter periods, and that deeper dives lasted longer (Figure 2).

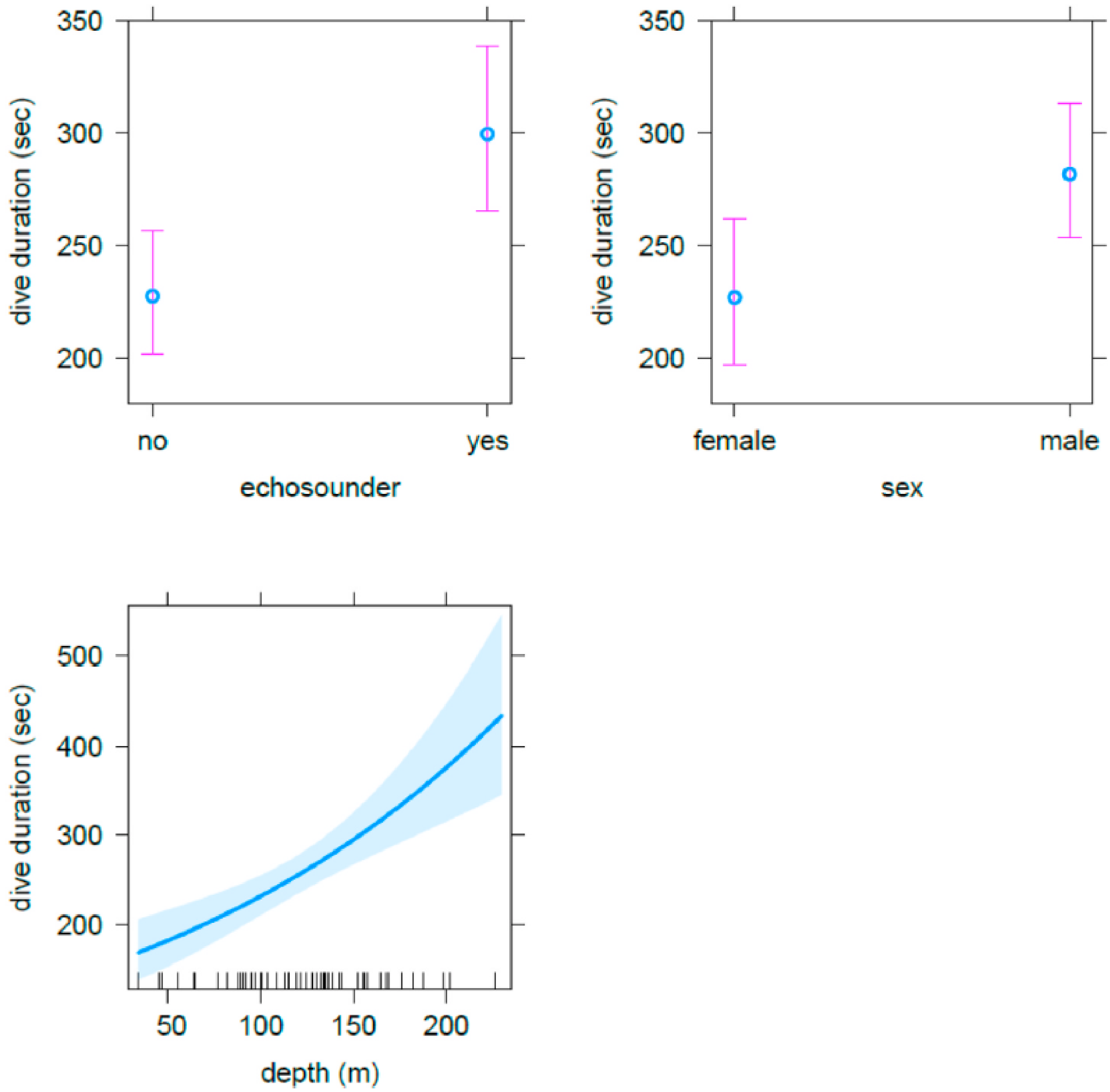

Figure 3 | Graphs of the effects of echosounder signal (top left, vessel distance (top right), noise level (bottom left), and dive depth (bottom right) on the rate of descent of prey capture dives.

DISCUSSION

In this study we investigated the relationship between vessel disturbance and killer whale behavior using high-resolution multi-sensor suction cup tags. Specifically, we tested whether vessel count, speed and distance, received noise level (for the whale), echosounder signal presence, and salmon abundance significantly affected the probability of prey capture.

About half of the recorded dives involved successful prey capture. We could tell this by the quick lurches, sudden changes in direction, and jerking movements recorded by the Dtags. The others involved echolocating in search of prey and initiating pursuit, but without jerking, rolling, buzzing, or changing directions quickly.

Southern resident killer whales were less likely to capture prey when the Chinook abundance was low and when nearby vessel speed increased (Figures 2 and 3).

There are a few explanations for the reduced probability of orcas capturing salmon when boats are going faster. The volume of boat noise increases with speed and is the greatest source of noise received by killer whales (Houghton et al. 2015; Holt et al. 2017; Joy et al. 2019; MacGillivray et al. 2019). Noise could interfere with the whales' use of echolocation during foraging, which is essential to finding and capturing prey (Barrett-Lennard et al. 1996; Holt et al. 2019).

While vessel speed had a significant effect on capturing prey, noise level at the whale did not. This may be due to having to discard some of our noise data; the noise of water flowing over the Dtag added to the recorded noise, making those recordings invalid. This caused our sample size to be small. Adding additional Dtag samples would show a clearer picture of whether noise directly affects prey capture.

Faster boats may also cause orcas to pay extra attention during prey search dives, resulting in fewer deep foraging dives and less capture success.

Whales made longer dives to capture prey and descended more slowly at first when nearby boats emitted sonar, indicating prolonged effort to successfully hunt at depth (Figures 2 and 3). The sonar signal may interfere with echolocation clicks because the sonar frequency at 50kHz is right in the middle of the range of orca echolocation clicks from 10-65 kHz (Figure 1), a problem called acoustic masking. The orcas may also be distracted by the vessel sonar, which has caused pilot whales to change direction in a previous study (Quick et al. 2016).

Whales descended more quickly at the start of dives when boats were closer and when the noise was higher, a common avoidance response to noisy, close vessels.

The amount of salmon available affected prey capture success, showing that resident orcas are limited by the decreased abundance of Chinook. We used Chinook number estimates from the Fraser River, which doesn't account for those heading for the Skagit or other smaller rivers, but is a good indicator of the amount available. Prey availability and disturbance from vessels and noise are threats that are suspected to interact with one another because of the whales' reliance on sound to hunt their core summer habitat, that happens to be full of vessel traffic (NMFS 2016; Murray et al 2021). Not having enough food can prevent whales from meeting their energy requirements, decreasing growth and reproduction.

Here, we provide evidence of an interplay between prey abundance and vessel disturbance that can limit access to food. In an orca population which has failed to recover since it was given the endangered species status, this has significant implications for management. In particular, vessel regulations have been implemented by governments to protect killer whales from vessel disturbance and sound (Holt et al. 2021). Furthermore, the consequences of underwater noise and vessel presence have been identified as an urgent research need to support orcas (Murray et al. 2021).

Though we offer reasonable explanations for our findings that vessels affect orcas ability to find enough food, we urge caution in assigning cause and effect relationships. As in any scientific study, it is possible that other, unmeasured variables are also at play. It is thus important to conduct more field-based research to inform management of endangered species, especially when deciding on efforts to increase salmon abundance and regulate vessels (NOAA 2019; Southern Resident Orca Task Force 2019).

Moreover, these results contribute to a growing awareness of the negative consequences of vessels on marine wildlife in an urban coastal corridor used for a variety of human activities, confirm the prey-disturbance threat interaction in endangered killer whales, and are the first to demonstrate a potential effect of echosounder signals on foraging behavior.

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