Slow down but level up: to address ship strikes, we need more than speed limits

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ABSTRACT

Shipping speed reductions have been and should remain a key strategy for reducing whale-ship strikes, but using them to justify additional shipping is questionable. Here we review what is known – and what is not – about the efficacy of speed mitigation in reducing vessel collisions and/or their lethality. We found 30 papers that present original evidence on this issue, half of which pertained to whale-watching. Of the remaining papers, the majority reported negative, ambivalent, or highly context-dependent evidence of avoidance or reduced ship-strike lethality. The most compelling support was found for North Atlantic right whales and humpback whales, but even for these species, there were also studies with negative results. For the other species that have been studied (n = 4), evidence is too limited to be conclusive but suggests that avoidance is uncommon to rare. On balance, while speed reductions probably do reduce strike rates and lethality in some whale species, those rates likely remain high, even at low speeds, apparently more probable than not for ships at speeds as low as 8–9 kn. Avoidance is less understood than lethality at this juncture, but overall our knowledge of whale-ship interactions is so sparse and mixed that speed controls alone ought not be equated with legal compliance. Instead, they should be treated within management contexts as a sensible but unverified hypothesis. Practically, this means that speed controls should always be used in tandem with other operational mitigations, and their efficacy should never be assumed. Robust monitoring should be required whenever speed mitigations are used.

KEYWORDS: SHIPPING; SPEED REDUCTIONS; SHIP STRIKES; WHALES; AVOIDANCE; BEHAVIOURAL RESPONSE

INTRODUCTION

Whale-vessel collisions (hereafter, 'ship strikes') have emerged as one of the most urgent mortal threats to whales globally (Thomas *et al*., 2015; Nisi *et al*; 2024). This is particularly true in US and Canadian waters, which are widely recognised as home to important habitats for many endangered and threatened cetaceans (Thomas *et al*., 2015), comprehensive federal protections for marine mammals (Nelms *et al*., 2021), and burgeoning marine traffic, including some of the busiest shipping lanes in the world (Pirotta *et al*., 2019). In fact, ship strikes may already be reducing whale populations along the Pacific coast (Rockwood *et al*., 2017) and have contributed to the decline of North Atlantic Right Whales (NARW; *Eubalaena glacialis*) along the Atlantic coast (NOAA, 2022). For coastal industries to operate in these waters and remain compliant with federal laws, their vessels must find

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ways to eliminate or at least limit harms to whales and other marine mammals (Marine Mammal Protection Act [MMPA] 1972; Endangered Species Act [ESA] 1973; Species At Risk Act [SARA] 2002).

Many actions have the potential, either directly or indirectly, to reduce strikes in certain shipping contexts, including but limited to improved data collection and reporting, observer programmes, new technologies that enhance whale detection at sea, deterrent devices, propeller guides, avoidance training for mariners, and education and outreach (IMO, 2009; IWC, 2017; Gende *et al*., 2019; Schoeman, 2020). In terms of shipping operations, the best ways to reduce strike risk are to adjust schedules and routes so as to minimise the spatial and temporal overlap of marine traffic and whales in high-risk areas (Schoeman, 2020). Such lane adjustments have been successfully established in a small minority of coastal shipping hotspots worldwide (Schoeman *et al*., 2020; Nisi *et al*., 2024), but it is broadly understood that they do not bring whale-ship overlap to zero. Even when and where such mitigations do exist, and most importantly in the cases in which they do not, there remains a need to reduce the remainder of risk via further operational adjustments.

Speed reductions and/or speed limits (hereafter, 'speed controls') are the measure most frequently proposed for mitigating ship strikes once shipping operations commence (e.g., IMO, 2009; Gende *et al*., 2011; Lageuex *et al*., 2011; Conn & Silber, 2013; Van der Hoop *et al*., 2014; McKenna *et al*., 2015; IWC, 2017; Rockwood *et al*., 2020). Active whale avoidance by mariners is also a recurring option (Webb & Gende, 2015; Williams *et al*., 2016; Gende *et al*., 2019; Helm *et al*., 2023), but it is generally infeasible for large ships and therefore does not approach the same prevalence or degree of industry-wide consideration as speed controls (Nisi *et al*., 2024). Speed controls also reduce ocean noise (Viers *et al*., 2018) and greenhouse gas emissions (Corbett & Fischbeck, 1997), adding to their attractiveness as a go-to mitigation for shipping management.

The premise that speed controls are effective makes logical sense: slower speeds give whales and ships more time to detect and avoid one another, and if a collision does occur, slower speeds may reduce the severity of any injuries. That logic has been supported by a core series of studies that, despite the mixed and nuanced nature of their results, have been referenced in turn by a generation of ship-strike modeling studies. On occasion, these studies have been cited as primary sources in management plans for protected species and environmental assessment certificates issued by governments to shipping projects worldwide (Lima *et al*., 2015). Some of those modeling studies have been conservation-oriented, in which mortality rates are predicted in order to highlight the potential severity of the ship-strike issue (e.g., Rockwood *et al*., 2017; Nichol *et al*., 2017; Keen *et al*., 2023; Nisi *et al*., 2024, Blondin *et al*., 2025) or in which slow-down measures are encouraged by demonstrating their potential benefits through predictive models of risk reduction (e.g., Rockwood *et al*. 2020; Ebdon *et al*. 2020; Keen *et al*. 2023; Blondin *et al*. 2025). In other sectors, the ship-strike literature regarding slow-down benefits is invoked to argue for the compatibility of new shipping projects with important whale habitat (e.g., Enbridge, 2010; TERMPOL, 2015).

In both cases, it is not unusual to see ship-strike findings from older papers, such as a particular speed-risk relationship for a given species, applied to new geographic contexts and unrelated whale populations, often without justification or adequate qualification (e.g., Enbridge, 2010; Rockwood *et al*., 2020). While such a choice may be valid in certain contexts, it does raise important questions about the generalisability of ship-strike findings. Two assumptions appear to be gaining prevalence in the ship-strike research and management community: (1) that speed controls work for any species anywhere, and (2) that they are effective enough to bring shipping projects into compliance with federal laws or other management targets, where applicable, no matter the shipping density. While we acknowledge that speed controls are sensible and probably effective, our central question here is whether or not they do *enough*. Do speed controls suffice to avoid unlawful and/or unsustainable rates of strike?

We are especially interested in answering this question in contexts where additional traffic is being proposed, especially within the habitat of federally protected whale species, in which speed control commitments may be needed in order to obtain government approval for increased shipping (e.g., Enbridge, 2010). Such calculus hinges entirely upon the notion that new regional speed controls work well enough to offset the risks imposed by additional transits from new shipping projects. If those assumptions are wrong, the number of strikes will rise instead of fall, and the opportunity to demand additional mitigation measures prior to project approval will be lost.

The more that speed controls are pushed as a panacea to the ship strike problem, the more careful we should be to understand the supporting evidence and its limitations. Here we set out to review that evidence in order to evaluate what is known and not known about the efficacy of speed mitigation in addressing the ship-strike problem, specifically with respect to rates of avoidance and lethality.

METHODS

We searched for all peer-reviewed literature with original evidence related to whale avoidance and the effects of various transit speeds on whale-vessel interactions. We did not include studies about the behavioural responses of cetaceans to anthropogenic noise, unless the paper specifically involved interactions with passing vessels, nor did we include studies pertaining to active avoidance of whales by mariners (see Gende *et al*., 2019 and references therein), as this is an aspect of the ship-strike dynamic that should be considered separately from whale-driven avoidance (Blondin *et al*., 2025). We confined our search to any cetacean that are the size of killer whales or larger.

To find studies, we used Google Scholar with search keywords that included various permutations of the following phrases, in alphabetical order: 'ship strike', 'ship strike lethality', 'shipping impacts on marine mammals', 'speed reductions and ship strikes', 'whale vessel collision', 'whale ship avoidance', and 'whale watching impacts'. From there, we reviewed the 'Literature Cited' sections of all papers we found as well as the papers returned in Google Scholar's 'Cited By' feature.

As we processed each paper, we paid special attention to the whale species and demographics involved; the region and season of data collection; the vessel types, sizes and speeds involved; and the evidence underlying any interpretations of behavioural response to nearby vessels. We then binned the papers into two groups *sensu* Argüelles *et al*. (2021): (1) studies of 'typical' marine traffic, i.e., vessels linearly transiting the area without stopping; and (2) studies with whale-watching vessels, which constitute an unusual type of interaction in which vessels tend to linger for extended periods of time and approach whales slowly. Within each of these groups, we then sorted the papers into categories of evidence for speed-dependence along the following continuum: (a) No apparent disturbance or avoidance observed, regardless of speed; (b) Limited, mixed or inconclusive evidence of avoidance; (c) Evidence of avoidance and its speed-dependence; and (d) Reduced mortality at lower speeds due to successful avoidance, reduced lethality of collisions, or a combination thereof.

RESULTS

Our search criteria returned 30 papers, one of which (Conn & Silber, 2013) contained separate and distinct analyses, one focused on avoidance, and one focused on lethality, each yielding important results. We therefore counted each analysis as a separate study for our purposes here, leading to a sample size of 17 studies of linearly transiting vessels and 14 studies of whale-watching interactions. In the former category, which is our focus here, four studies reported no apparent response or avoidance to vessel encounters (1a); seven studies reported limited/mixed/inconclusive evidence of speed-dependent avoidance (1b); one study reported regular avoidance (1c); and five studies found evidence that lethality rates were speed-dependent but remained high for most species and speeds in the studies with the largest sample sizes (1d) (Fig. 1).

No apparent response or avoidance

Four studies (24%) found no evidence of disturbance response (Nowacek *et al*., 2004; Argüelles *et al*., 2021; Dunlop, 2024) or avoidance behaviour (Williams *et al*., 2014) during close encounters with vessels. Argüelles *et al*. (2021) found little to no response of southern right whales (*Eubalaena australis*) to a 5.6 m research vessel traveling at 6 kn during line-transect surveys off Argentina (n = 971 whale encounters over 34 trips between 2013 and 2015).

In coastal Australia, Dunlop (2024) observed experimental approaches (n = 31) to humpback whales by vessels 19-65 m in length travelling at speeds ranging from 0.55-5.5 kn. When comparing their movements and behaviours to control periods (n = 94), Dunlop found that most groups were unresponsive, often requiring

approaching vessels to take evasive action, and concluded that humpbacks are not likely to take sufficient action to avoid a collision.

Nowacek *et al*. (2004) reported similarly in a study of 10 individual) NARWs fitted with D-tags in Bay of Fundy, Canada, who were exposed to vessel noise and other acoustic stimuli using an underwater speaker. Vessel noise did not induce any form of response, but 'alert stimuli' did cause five of the six exposed whales to abandon dives, return quickly to the surface, and remain at or just under the surface for the duration of the playback, ironically increasing their exposure to ship strike.

Williams *et al*. (2014) found that northern resident orca (n = 181 tracks of 25 individuals) regularly exhibited a wide variety of disturbance behaviour in response to nearby boat traffic as well as experimental approaches (n = 40) by a 5.2 m research vessel, but that these responses did not result in effective avoidance. Note that all these studies involved relatively small boats (5.2-65 m), and it is not clear how these results would translate to larger ships.

Limited, mixed or inconclusive evidence of avoidance

Seven studies (41%) offered ambivalent or very limited results on the matter speed-dependent avoidance. Two of these used archival databases for their analyses, while the remaining four involved dedicated fieldwork.

One of the analyses in Conn & Silber (2013) used an indirect approach to test for speed-dependent strike rates: they used an archival database of large whale ship strikes (1975-2012) to compare the speeds at which ships struck whales to the distribution of ship speeds off the US Atlantic Coast (archival Automatic Identification System [AIS] data from 2008-2012). Only 12 strikes aligned with this region and date range, and the species involved were not reported. Their Bayesian regression found that the ship strikes occurred at significantly higher speeds than expected based on the regional distribution of ship speeds, but sample size (n = 12) was insufficient to specify the shape or effect size of that regression's speed-probability curve.

A more recent databased-driven study, Winkler *et al*. (2020), referenced a separate ship-strike database maintained by the International Whaling Commission (IWC) and reported on strikes with large whales at relatively low speeds: of the 101 strikes in that record (1820–2019), while the majority occurred at speeds > = 15 kn (n = 72), more reported events occurred in the speed range of 0-9 kn (n = 15) than 10-14 kn (n = 14). This review did not include statistical analyses of these results.

Moving to fieldwork-based studies, Kite-Powell (2007) used real-time observations of NARW reactions to oncoming vessels (n = 37; vessel types, speeds and sizes not reported) to find that NARW avoidance responses were highly variable and context-dependent. The probability of avoidance depended in particular on the distance at which the whale detected the oncoming ship, such that a speed reduction from 20-25 kn to 10 kn would reduce the probability of collision by 40%, but whether or not that improvement is enough to make a strike improbable depends on the detection distance (DD); at DD = 50 m, for example, there is still a 100% chance of collision at 10 kn. Furthermore, DD is a function of many factors, involving whale behavioural state; visibility; the arrangement and disruptiveness of other stimuli in the environment; and the ability of whales to decipher directionality and proximity based on ship speed, size and angle of approach.

McKenna *et al*. (2015) tagged blue whales (*Balaenoptera musculus*, n = 9 individuals) near a Southern California shipping lane and observed behaviours during 20 transits of large ships (> 300 gross tons, traveling at 10-30 kn) within 3.6 km of the whales. In 55% of those transits, a limited avoidance response was observed, involving either sudden dives or delayed resurfacing. These behaviours were observed in eight of the nine tagged individuals. None of the whales steered clear of the shipping lanes while tagged.

David *et al*. (2021) observed near-miss events of fin whales (NMEs; encounters within 50 m ahead of vessel) with ferries (n = 238,499 km monitored between 2008 and 2019 on 13 ferry routes, platform heights 12–15 m, speeds 15–28 kn) transiting between Corsica and mainland Italy, Monaco, France and Spain in the Mediterranean Sea. They found that NMEs (n = 42 out of 2,775 whale encounters) were more common at higher ship speeds (mean 22.5 kn) compared to average transit speed (20.5 kn), but that only 44% of NMEs induced avoidance behaviour in the whales; the remainder continued traveling, resting or other.

Gende *et al*. (2011) used observers aboard transits (n = 380) of cruise ships (length range = 181–294 m) in southeast Alaska to compare the average distance of humpback whale detections (n = 891) from the ships at

various speeds (6–22 kn). They found that detection distance tended to increase at slower speeds, and it did so by a mean of 114 m around a threshold change point of 11.8 kn, with mean detections occurring at 448 m (95% credibility interval = 39 –485 m) at slower speeds and at 562 m (95% CI = 468–676 m) at higher speeds. They interpreted that change in mean detection distance as evidence of speed-dependent avoidance. However, we underscore the authors' own acknowledgement that using detection distance as a proxy for avoidance probability hinges on significant assumptions. Whales can still get hit, even as the average detection distance increases. It is possible, for example, that the whales who end up getting struck are those that are below-average at avoiding ships or are entirely naïve to ship speed (Lima *et al*., 2015). We note that it is also possible that sampling bias is influencing their results: faster ships provide less time for observers to spot whales, which may cause more distant groups to be under-reported at higher speeds. Average observer-whale detection distance may not correlate perfectly with whale-ship detection distance or ship-whale separation.

Currie *et al*. (2017) performed a similar study in coastal Hawaii during the humpback whale breeding and calving season, conducting line transects (n = 608 over 143 days) from an 8 m research vessel, yielding a total of 529 surprise encounters and 25 near misses with humpback whales. Their change-point analysis identified a speed threshold of 12.5 kn, with detections occurring a mean of 211 m and 189 m below and above that change point, respectively. The same caveats regarding Gende *et al*. (2011) apply here, and we note that the effect size (a mean difference of 22 m) is even smaller in this case.

Regular avoidance

Only one study (6%) reported consistent observations of whale avoidance of oncoming vessels: bowhead whales in the Beaufort Sea regularly reacted strongly to the approach of vessels (n = 5 approaches), both small (length 13–16 m, speed 7–20 kn, approach within 500 m) and large (65 m, speed and approach distance unreported), even when they were as far as 3.4 km away (Richardson *et al*., 1985). The authors observed that bowhead whales seemed more sensitive to vessel traffic than other species, and hypothesised that they were not acclimatised to vessel traffic in polar seas (see also Lagueux *et al*., 2011). It is worth noting, however, that this study involved only five vessel transits that took place 40 years ago at a single study site during a limited seasonal window.

Priyadarshana *et al*. (2016), a study we did not include in our sample, investigated blue whale-shipping overlap off the southern coast of Sri Lanka. Those authors reported an incidental finding, tangential to their primary results, that their modeled number of potential annual collisions in the study area, assuming no avoidance response, was 'an order of magnitude' greater than 'pessimistic estimates' from previous research (e.g., Randage *et al*., 2014). Although actual estimates were not provided, the model-estimate discrepancy they report is potentially indicative of avoidance. Along similar lines, it is also compelling that dozens of marine mammal surveys have covered hundreds of thousands of square kilometers of track worldwide in recent decades with very few strikes documented. Such observations align with the hypothesis, which is shared by Blondin *et al*. (2025) and which we do not dispute, that some unknown baseline level of avoidance is occurring at some unknown scale. However, those observations are unrelated to the question of a speed-risk relationship.

Reduced mortality

Five studies (29%) (Laist *et al*., 2001; Vanderlaan & Taggert, 2007; Conn & Silber, 2013; Laist *et al*., 2014; Garrison *et al*., 2025) reported evidence of reduced mortality as a result of lower transit speeds, which, as stated previously, can be a function of more frequent avoidance, less lethal collisions, or a combination thereof. The most recent and most comprehensive of these studies, Garrison *et al*. (2025), found that lethality risk remained high even at slow speeds, especially for large ships and for species other than humpback whales (see below). None of these papers used direct observations of whale-ship interactions but instead relied upon statistical analyses of databases of ship strikes, strandings, ship traffic and whale sightings to draw conclusions about the efficacy of reduced speeds.

Laist *et al*. (2001) was the first to report general trends from a review of worldwide reports of ship strikes across all large whale species throughout a historical database (1975–2002) (Jense *et al*. 2003). They did not perform statistics on speed effects; they reported anecdotally that most reported strikes with speed data

(n = 47) occurred at speeds 14 kn or faster, though strikes and severe injuries occurred at speeds as slow as 6 kn and mortalities were observed as slow as 10 kn.

Vanderlaan & Taggert (2007) used the same 1975-2002 database from Laist *et al*. (2001) to develop a statistical model of strike lethality. Their focus was NARW, but their statistical model used incidents primarily from other species (ranked by descending sample size: unknown species [n = 14], humpback whale [n = 12], gray whale [n = 4], fin whale [n = 3], minke whale [n = 3], NARW [n = 3], sperm whale [n = 3], Bryde's whale [n = 2], blue whale [n = 1], orca [n = 1]). Their model predicted that the probability of lethal strike declined at slower speeds, from a mean of 100% at > = 24 kn, to 60% at 13 kn, to 25% at 9kn, to < 5% at < 3 kn. Note, however, that sample sizes were low for slow speeds (n = 7 at < = 10 kn, 15% of dataset; n = 11 at < = 13kn, 23%), and those low-speed incidents involved vessels with a mean length of only 37 m (median = 24 m, min = 14 m, max = 115 m). Hence, this study cannot speak to the lethality of most commercial ships at slow speeds. Note also that no single species had an adequate representation of lethal and non-lethal outcomes sufficient for drawing species-specific conclusions; for example, the most-represented species in the study, humpback whales (n = 12 out of 47), had only one instance of mortality (at 19 kn).

Conn & Silber (2013) built upon the dataset used in Vanderlaan & Taggert (2007; n = 47) by adding five additional strikes from a conference poster and 38 previously unpublished strikes that occurred between 2007 and 2013 (species not reported). Their updated model (n = 90) predicted a higher risk than its predecessor in Vanderlaan & Taggert (2007): approximately 75% at 13 kn (95% credibility interval = 55-85%) and 55% at 9kn (95% CI = 35-70%). Conn & Silber then used these results to predict the reduced harms to right whales of the mandatory speed restrictions announced by NOAA in late 2008 within Seasonal Management Areas (SMAs) off the US eastern seaboard.

Similarly, Laist *et al*. (2014) estimated the reduced harms of the 2008 SMA launch by analysing stranding data for right whales and humpback whales on the eastern US coast. In an 18-year period prior to the implementation of the SMAs, 13 right whale strandings and 12 humpback strandings were attributed to ship strikes. In the five years immediately following SMA implementation, no stranded whale with death attributable to ship strike, of either species, was found in or near the SMAs. Bootstrap statistics indicated a statistical significance of p = 0.013, but the authors also acknowledged that: (1) more time was needed to confirm the pattern they were detecting; (2) strandings involve stochastic processes whose predictability are complicated by a myriad of dynamic oceanographic and ecological variables; and (3) their results differ from Pace (2011) that evaluated the impacts of the 2008 speed rule using a comparison of the time interval between reports of ship strike mortalities in northeast US waters in the 10 years prior to the 2008 speed rule and the two years following. He found no evidence for lower rates of strikes in 2009-10.

Garrison *et al*. (2025) updated the analysis in Conn & Silber (2013) by increasing the sample size of whale-vessel interactions with known outcomes to 201 (80 cases with severe injury or mortality; 121 cases with no severe injury), which allowed their strike lethality model to account for vessel size. Their best-fitting model also distinguished between risk to humpback whales, the species with the largest sample size (n = 133, 66% of total cases, including 29 cases of severe injury/mortality and 104 cases without severe injury), and all other species. The species with the next-highest representation in the dataset were the fin whale and NARW (n = 12 each). Due in part to these vessel and species covariates, their model indicated that mortality was significantly more likely than previously thought for most species, with *P(Lethality)* > 0.80 for all speeds above 5 kn for ships > 108 m in length. At 10 kn, a common target for speed restrictions, *P(Lethality)* for these large ships was 0.88. Even for 'medium' sized vessels (12.1–19.7 m), *P(Lethality)* was more likely than not at 12 kn. In contrast, humpback whales appeared to face lower risks across all vessel size classes; for example, *P(Lethality)* was 0.67 and 0.71 for ships > 108 m at 5 and 10 kn, respectively, and 0.18 for vessels 12.1–19.7 m at 12 kn.

Species sample sizes

Many of the studies we found (n = 6) focused on NARWs. It is noteworthy that several studies focused on NARW are in fact based on non-independent datasets (i.e., they use some of the same data) in which the majority of data are from other species, so it is difficult to know how much 'weight' to give each individual paper and also

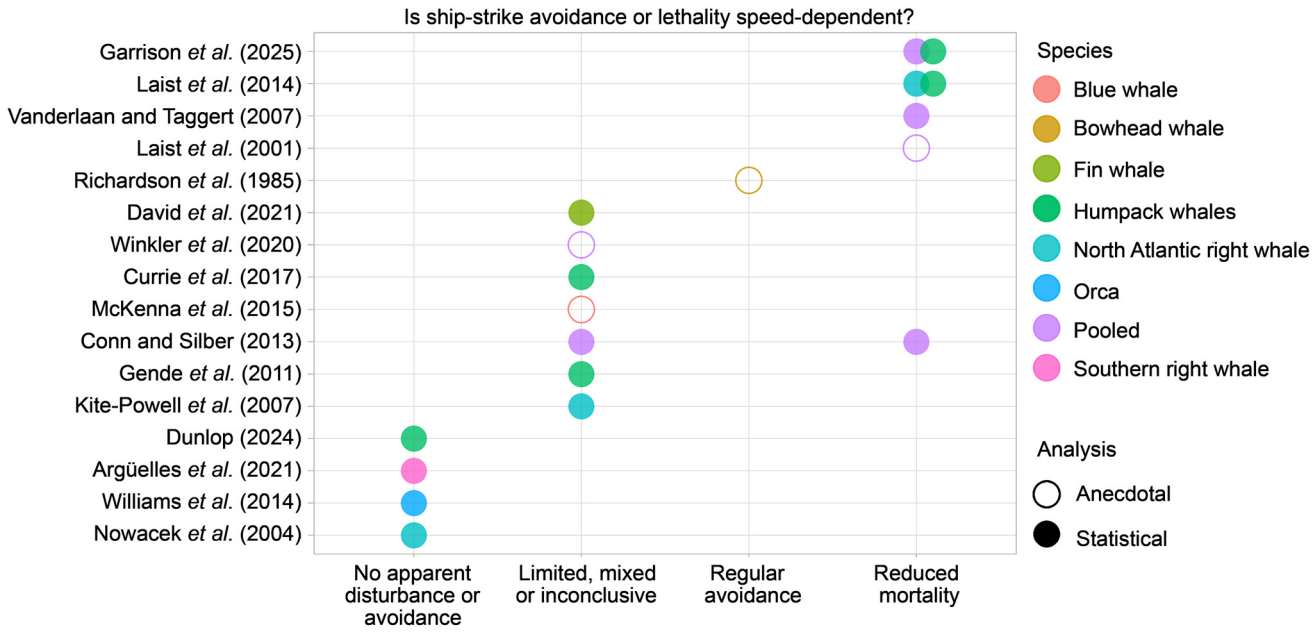

Figure 1. Summary of literature relevant to the speed-dependence of ship-strike avoidance or lethality for non-whale-watching vessels.

how to interpret the results with respect to NARW conservation. Two studies focused specifically upon humpback whales. In the pooled-species studies that reported species-specific sample sizes (Laist *et al*., 2001; Vanderlaan & Tagger, 2007; Laist *et al*., 2014; Garrison *et al*., 2025), the humpback whale was the best-represented, followed by NARW and fin whales.

Whale watching

While whale watching interactions are not the focus of this paper, it is noteworthy that the 14 relevant papers we found on whale-watching were limited to only two categories of evidence: (2a) evidence of disturbance but not avoidance (n = 10; Gorden *et al*. 1992; Corkeron, 1995; Williams *et al*., 2002; Jahoda *et al*., 2003; Scheidat *et al*., 2004; Morete *et al*., 2007; Williams & Ashe, 2007; Noren *et al*., 2009; Schuler *et al*., 2019; Currie *et al*., 2021); and (2b) limited or mixed evidence of avoidance (Baker & Herman, 1989; Stamation *et al*., 2010; Argüelles *et al*., 2016; Arias *et al*., 2018). None presented evidence of regular avoidance. Half of these papers were focused on humpback whales in Australia (Corkeron, 1995; Stamation *et al*., 2010), Ecuador (Scheidat *et al*., 2004), Brazil (Morete *et al*., 2007), Alaska (Baker & Herman, 1989; Schuler *et al*., 2019), and Hawaii (Currie *et al*., 2021), but Southern right whales off Argentina (Argüelles *et al*., 2016; Arias *et al*., 2018), sperm whales off New Zealand (Gordon *et al*., 1992), fin whales in the Mediterranean (Jahoda *et al*., 2003), and orca in the Canadian Pacific (Williams *et al*., 2002; Williams & Ashe, 2007; Noren *et al*., 2009) were also studied.

DISCUSSION

Roughly half of the literature on the topic of whale avoidance and the effects of speed reductions is devoted to whale-watching studies. For our purposes, however, their use is extremely limited for two reasons: (a) such interactions are so distinct that they likely cannot be applied to typical marine traffic, i.e., linearly transiting vessels (Lima *et al*., 2015); and even if they could, (b) the evidence for avoidance in whale-watching interactions ranges from poor to mixed across all species studied. We conclude that the whale-watching literature to date cannot be used as support for speed controls as a ship-strike mitigation measure.

The most compelling evidence we found for speed-dependent *strike rates* (i.e., avoidance) comes from Kite-Powell *et al*. (2007). Note, however, that this study (a) focused specifically on a single species (NARW) in a single region (US Atlantic coast); (b) was based on interactions with vessels of unreported size and type; (c) reported that chances of avoidance are strongly dependent on the wide variety of factors that influence detection distance;

and (d) reported that strikes can still be very likely even at low vessel speeds. The second-most compelling study (Conn & Silber, 2003), hinges on a sample of just 12 strikes from a single region (species unreported).

The three most-frequently cited studies related to speed-dependent lethality – Vanderlaan & Taggert (2007), Conn & Silber (2013), and Laist *et al*. (2014) – are limited in important ways, and the studies that cite them should be interpreted with care. The lethality model in Vanderlaan & Taggert (2007) is based on a relatively small sample size (n = 47 strikes), especially for large ships at speeds < = 10 kn. It also relies on pooling species, with a large fraction (26%) of species unidentified. Likewise, Laist *et al*. (2014) is based on 25 strandings, a kind of event from which confident conclusions are difficult to draw, and is countered by a ship-strike database study (Pace, 2011) that finds little evidence for fewer strikes in the same region in a subset of the same time. The lethality model in Conn & Silber (2013) is the most robust of these three commonly-cited studies (sample size n = 90 cases), but it receives uneven treatment in the literature as the finding that lethality risk is reduced at slower speeds often overshadows the other finding that strikes can still be lethally dangerous even at low speeds.

To date, Garrison *et al*. (2025) provides the most authoritative statistical model of strike lethality. Their results indicate that: (a) large ships are much more lethal than previously estimated, even at speeds as low as 5 kn; (b) even small-to-medium vessels can deliver lethal strikes to large whales; and (c) the risk of mortality is species-dependent, with humpback whales appearing to be at lower risk than other species. While their speed-lethality model is the best currently available, future studies that use it should note that most of its data come from US waters and that data are scarce for all species other than humpback whales.

NARW is the only species with compelling evidence that speed controls facilitate avoidance, but even for this species, there were studies presenting negative and/or mixed. The second-best studied species is the humpback whale, and it also has weak evidence for avoidance, ranging from negative to ambivalent or inconclusive.

The only other species with any published evidence on avoidance are blue, bowhead, fin and killer whales. For these species, there is no strong evidence that avoidance occurs or that vessel speed makes a difference in their avoidance rate. Studies are too limited to be conclusive, but the evidence we have does not support the hypothesis that avoidance is common or speed-dependent. The exception is the bowhead whale, which may be possibly more sensitive and avoidant, though studies with larger spatiotemporal scope and sample sizes are needed to verify this.

The weak and negative evidence for these other species indicates that speed-related strike patterns observed in one species should never be assumed for another, despite the fact that this often occurs within the ship-strike literature and in shipping management.

Similarly, none of these species has been studied across multiple populations. Without any evidence that speed-risk relationships from one region can be assumed for another, such assumptions ought to be avoided when justifying additional shipping or, when necessary, e.g., for modeling mitigation scenarios for existing shipping, they should be presented with explicit qualification.

Sample sizes in this literature are small and geographically-limited. As examples, (a) the only study on blue whale avoidance (McKenna et al., 2015) involved nine tagged individuals and 20 transits of large ships within the same shipping lane; (b) the only study that found indirect evidence of humpback whale large-ship avoidance (Gende *et al*., 2011) pertains to a single type of ship (cruise ships) in a single waterway in Alaska; (c) Conn & Silber (2013) was based on only 12 strike reports; and (d) Garrison *et al*. (2025), the most comprehensive lethality study to date, was only able to include 17 cases of sublethal collisions for species other than humpback whales.

While very few studies relied on real-time ship-board observations of whale-vessel interactions, the ones that do are extremely informative (Kite-Powell *et al*., 2007; David, 2024). More ship-board observations across populations for multiple species in multiple regions should be a clear research priority.

The balance of our findings suggests that, while speed reductions probably do serve to reduce strike rates and lethality rates in some large whale species, those rates probably remain high even when ships are slower. Most importantly, current knowledge of whale-ship interactions is so sparse, mixed, and either overly species-specific or overly species-agnostic, that speed controls alone should never be assumed to suffice for keeping shipping operations within known whale habitat in compliance with management targets or federal protections of marine mammals.

In a poignant example, the lethality models in Garrison *et al*. (2025) were recently incorporated into an encounter-based ship-strike model by Blondin *et al*. (2025) who predicted that vessel strikes kill a mean of 17.5 NARW annually. The authors also simulated an ideal 'slow-all' scenario in which 100% of non-military vessels transiting above 10 kn were slowed to 9.5–10.0 kn, but that best-case-scenario change resulted in a mortality reduction of only 11% (15.5 per year). For context, Potential Biological Removal for this population is 0.7 NARW per year (Hayes *et al*., 2022).

Our literature review indicates that the benefit of speed controls is a sensible hypothesis with mixed empirical support from a few studies of only a few species in only a few regions. It therefore remains unverified, and it should be treated as such within a management context. Namely, we highlight several potential applications for shipping management contexts:

Acknowledging the uncertainties we have outlined here, speed controls should still remain a high-priority mitigation measure. They are likely to reduce strike and lethality risks to some degree, as the studies above suggest, and they have other guaranteed benefits, such as reduced noise and lower emissions.

Speed controls should always be used in tandem with other mitigations, never in isolation as the sole guard against strikes. Other promising measures, such as mariner training for active avoidance and daytime-only transits through important whale habitat, are beyond the scope of this study but are discussed at length elsewhere (e.g., IWC, 2017; Gende *et al*., 2019; Pirotta *et al*., 2019; Schoeman *et al*., 2020; Keen *et al*., 2023; Nisi *et al*., 2024).

The efficacy of speed controls, as with any unvetted mitigation measure, should never be assumed. Instead, robust monitoring for strikes and avoidance should be required for every project for which speed controls are proposed. To be clear, in the case of preexisting shipping operations, monitoring programme development should never delay the implementation of speed controls. However, any plans or proposals for additional shipping need appropriate monitoring to be in place before operations begin. This is especially true for those species and regions that are underrepresented in Garrison *et al*. (2025) (i.e., any species other than humpback whales and any region outside the U.S.A. Exclusive Economic Zone, EEZ). The exact nature of these monitoring programmes is beyond the scope of this study but may include some or all of the following elements: (a) transparent, timely, accessible and affordable data on marine traffic activities; (b) dedicated marine mammal observers stationed on flying bridge, bow, and/or stern during transits of important whale habitat (Gende *et al*., 2016; Helm *et al*., 2023); (c) video monitoring of the bow and stern areas for archival reference; (d) impact sensors along ship hulls; and (e) thermal imaging systems to quantify rates of whale avoidance ahead of the vessel (Baille & Zitterbart, 2022). We acknowledge that whale-ship avoidance dynamics are nuanced and extremely difficult to study, but that fact should not be used to justify ignoring the issue; instead, it should mobilise sustained and dedicated investment in the research.

Whenever the benefits of slow-down measures are modeled for an area with pre-existing traffic, analysts should take care (a) to emphasise any assumptions and uncertainties involved at each stage of the ship-strike model, especially when avoidance or lethality models from studies of other species and/or other regions are being applied in a new context; and (b) to report a precautionary version of their model in addition to the version in which all assumptions are included. For example, if ship-strike rates are being estimated for a species and/or region that is poorly represented in the literature reviewed here, a precautionary version of the model should also be included, in which avoidance is not assumed and *P(Lethality)* is conservatively high at all speeds and for all vessel types.

Whenever new or expanded shipping activities are proposed for a management area, the impacts of speed controls should be modelled with precautionary simulations, such as model versions in which encounter rates assume no avoidance, before environmental assessment permits are granted. This would avoid the possibility that landmark studies such as Kite-Powell *et al*. (2007), Vanderlaan & Taggert (2007), Conn & Silber (2013), and Garrison *et al*. (2025) are cited inappropriately. While we emphasised above that these studies are geographically limited and may not be appropriate for data-poor species, they remain useful when applied within a precautionary framework and interpreted with care, since they demonstrate that substantial and perhaps unacceptable residual risk may still persist even when speed targets are met (Blondin *et al*., 2025).

Most importantly, speed controls must be considered in the context of management targets. On the high seas or in jurisdictions without take limits, speed controls should always be encouraged, especially within known whale habitat. Whenever possible, the efficacy of these speed reductions should be monitored, analysed and shared. But for those waters in which federal laws protect endangered and threatened marine mammals, such as the EEZs of the US and Canada, lethal harm to protected species is illegal (MMPA 1972; ESA 1973; SARA 2002). In such contexts, the burden should be on industries to both (1) adjust operations as needed to comply with those laws; and (2) facilitate monitoring of their own activities to ensure they remain compliant. This holds for preexisting operations but especially for prospective additional operations, which as a general rule should not be approved within the habitat of protected species unless speed controls are paired with robust monitoring and additional forms of mitigation.

To address the knowledge and monitoring gaps discussed here, we see enormous potential for stronger collaborations between the shipping industry and research community. We encourage the commercial shipping industry to invest in observer teams, technological systems, and third-party oversight in order to monitor all whale interactions, near-miss events and collisions in a transparent manner as part of day-to-day operations.

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