Received: 18 March 2021 | Revised: 30 June 2021 | Accepted: 1 July 2021

DOI: 10.1111/gcb.15798

PRIMARY RESEARCH ARTICLE

Global Change Biology WILEY

A Gulf in lockdown: How an enforced ban on recreational vessels increased dolphin and fish communication ranges

Matthew K. Pine[1] | Louise Wilson[2] | Andrew G. Jeffs[2] | Lauren McWhinnie[3,4] | Francis Juanes[1] | Alessia Scuderi[5,6] | Craig A. Radford[2]

[1]Department of Biology, University of Victoria, Victoria, BC, Canada

[2]Institute of Marine Science, University of Auckland, Auckland, New Zealand

[3]School of Energy, Geoscience, Infrastructure and Society, Heriot-Watt University, Edinburgh, UK

[4]Department of Geography, University of Victoria, Victoria, BC, Canada

[5]Marine and Environmental Science Faculty, University of Cádiz, Cádiz, Spain

[6]Association Nereide, Cádiz, Spain

Correspondence
Matthew K. Pine, Department of Biology, University of Victoria, Victoria, BC, Canada.
Email: mattpine@uvic.ca

Funding support was from Hauraki Gulf Cetacean Fund, by the Director-General of Conservation at the Department of Conservation, New Zealand.

[Correction added on 4 August 2021, after first online publication: Author name 'Sceuderi' has been corrected to 'Scuderi'.]

Abstract

From midnight of 26 March 2020, New Zealand became one of the first countries to enter a strict lockdown to combat the spread of COVID-19. The lockdown banned all non-essential services and travel both on land and sea. Overnight, the country's busiest coastal waterway, the Hauraki Gulf Marine Park, became devoid of almost all recreational and non-essential commercial vessels. An almost instant change in the marine soundscape ensued, with ambient sound levels in busy channels dropping nearly threefold the first 12 h. This sudden drop led fish and dolphins to experience an immediate increase in their communication ranges by up to an estimated 65%. Very low vessel activity during the lockdown (indicated by the presence of vessel noise over the day) revealed new insights into cumulative noise effects from vessels on auditory masking. For example, at sites nearer Auckland City, communication ranges increased approximately 18 m (22%) or 50 m (11%) for every 10% decrease in vessel activity for fish and dolphins, respectively. However, further from the city and in deeper water, these communication ranges were increased by approximately 13 m (31%) or 510 m (20%). These new data demonstrate how noise from small vessels can impact underwater soundscapes and how marine animals will have to adapt to ever-growing noise pollution.

KEYWORDS
acoustics, anthropogenic noise, communication range, COVID-19, dolphins, marine mammals, masking, vessels

1 | INTRODUCTION

Because of the COVID-19 pandemic, many countries around the world entered into various forms of 'lockdowns' to combat the spread of the novel coronavirus. Borders were closed, freedom of movement and commerce was heavily restricted and international trade substantially reduced within months (Bates et al., 2020), bringing about the 'Anthropause' (Rutz et al., 2020). This presented researchers around the world an unprecedented setting to quantify the effects of human activity on wildlife (Bennett et al., 2020; Patrício Silva et al., 2020; Rutz et al., 2020). Although the socio-economic impacts were severe and widely felt, urban wildlife responded to the sudden cessation of human activities (Bates et al., 2021). News reports of wildlife invading urban areas quickly ensued: pumas spotted in downtown Santiago; jackals on the streets of Tel Aviv; goats along deserted highways in Istanbul; fallow deer in London; grey langurs in Ahmedabad, India, and many others (Rutz et al., 2020). Perhaps more hidden from view, but still noticed, was the response of coastal marine organisms to this new, relative calm (Rutz et al., 2020).

One potential key factor in explaining this observed change in wildlife behaviour during the 'lockdown' is the reduction of anthropogenic noise in the environment. Noise pollution is the most pervasive by-product of urbanisation, transport and industry, that changes the acoustic environment which many animals are acutely tuned to (Shannon et al., 2016). On land, the 'quiet' brought about by COVID-19 pandemic management measures led to an immediate drop in urban noise pollution (Mandal & Pal, 2020) and 50% drop in seismic noise (Lecocq et al., 2020). There was also a 1.5 dB re 1 μPa drop in underwater noise levels off Vancouver Island, Canada, due to reduced shipping (Thomson & Barclay, 2020).

Marine mammals, fish and invertebrates depend on sound for critical life history processes, such as mate selection and predator avoidance (Peng et al., 2015). Anthropogenic underwater noise has been increasing around the world for decades (Andrew et al., 2011; Frisk, 2012). Rising underwater noise levels in coastal environments due to small boats has become of substantial concern due to growing evidence of both lethal and sublethal impacts on marine life (Hawkins & Popper, 2014; Hermannsen et al., 2019; Jones, 2019; Popper & Hawkins, 2019). This is particularly relevant in highly productive waters that are near major port-cities, such as the Salish Sea near Vancouver (Cominelli et al., 2018; Joy et al., 2019), the Pearl River Estuary near Hong Kong (Pine et al., 2017; Sims et al., 2012) and the Hauraki Gulf near Auckland (Pine et al., 2016; Putland et al., 2018). A common threat facing these productive waters is increasing levels of vessel noise from an increasing volume of commercial and recreational marine traffic (Dolman & Jasny, 2015; Farcas et al., 2020; Hildebrand, 2009; Luís et al., 2014; McWhinnie et al., 2017; Pine et al., 2016; Simmonds et al., 2014; Weilgart, 2007). For example, Auckland, which is New Zealand's largest city, is located within the centre of the Hauraki Gulf Marine Park (HGMP), an area of 4000 km^2 with outstanding marine biodiversity including >700 species of marine intertidal invertebrates, >80 species of fish and 25 species of marine mammals, at least six of which are resident (Hauraki Gulf Forum, 2014). Auckland residents have the highest recreational vessel ownership per capita in the world, and in 2011, boat ownership was estimated to be 132,000, with numbers expected to reach 183,000 by 2041 (Beca, 2012).

Recent research has shown that increasing vessel noise reduces the ability of dolphins and fish to effectively perceive their acoustic environment (Erbe et al., 2016, 2019; Putland et al., 2018; Stanley et al., 2017). The primary mechanism for this is auditory masking (Erbe et al., 2016; Slabbekoorn et al., 2010). Vessel noise commonly masks natural sounds as the broad frequency range of vessel noise strongly overlaps many abiotic, such as rain and wind, and biotic sounds from animals, especially dolphins and fishes (Mooney et al., 2020; Slabbekoorn et al., 2010). Masking of dolphin whistles, buzzes and echolocation clicks, or grunts, pops, clicks and hums from fishes have all been linked to a range of impacts, as acoustic signalling is involved in navigation, foraging, mating, socializing and avoiding dangers (Au & Hastings, 2008).

On 26 March 2020, New Zealand entered a strict lockdown of societal activity to combat the spread of COVID-19, with the government placing a complete ban on all non-essential services on both land and sea. Vessel activity in the HGMP abruptly declined, with all recreational and non-essential commercial vessels banned from operating for 7 weeks. Shipping and related vessels continued to operate, but traffic was heavily reduced. For example, automated identification system records for vessels within a 10-km radius around the Noises Islands, showed an approximate 58% decrease during the 7-week lockdown period (L. Wilson, unpublished data). For the HGMP's marine animals that depend on underwater sound for critical life history processes, the reduction in vessel traffic resulted in significant changes to their acoustic habitat.

2 | MATERIALS AND METHODS

2.1 | Acoustic data

Acoustic data were gathered between February and May 2020 using seafloor-mounted acoustic recording stations (ST300HF, Ocean Instruments NZ) at five sites within the Hauraki Gulf, northern New Zealand (Figure 1). Recorders captured a 2-min sample of ambient sound (digitized to a.WAV file) every 10 min at a 48-kHz sampling rate and high gain setting. Deployment was 2 months prior to community lockdown due to COVID-19 that started at 23:59 h on 25 March 2020. The acoustic recorders were field-calibrated before and after deployment using a calibrated piston phone (G.R.A.S Type 42AA, 250 Hz @ 114 dB) and a sound level meter (Brüel & Kjaer 2250 Type 1 SLM with a Bruel & Kjaer ½ condenser microphone Type 4189 and calibrated with a Brüel & Kjaer Type 4231 sound calibrator). Each recorder was located in open water in frequented vessel routes that were of varying distances from Auckland City. The Rangitoto Channel site (Figure 1) was located in the Rangitoto Channel at a depth of 14–17 m to capture the changes in vessel activity within a major thoroughfare for both recreational and commercial marine traffic. Three sites were located at varying distances offshore of Auckland City's northern suburbs, that is, Long Bay (silty-seafloor, 13–17 m depth), Shearer Rock (rocky reef, 17–20 m depth) and the Ahaaha Rocks (sandy seafloor, 34–37 m depth). The fifth site was offshore in the centre of the Hauraki Gulf, approximately 45 km from the central business district of Auckland City, and named Mid-Gulf (sandy seafloor, 47–50 m depth).

2.2 | Weather data

Hourly wind speeds (km/h) and direction were continuously logged at a weather station (operated by the National Institute of Water and Atmosphere [NIWA]) located at 318 m above the central business district in Auckland City on the Sky Tower building (S 36.85004°S, 174.76242°E). This was selected in favour of other weather stations at sea level because it had omnidirectional exposure to the wind flow that was also present at the acoustic recording sites between ~9 and 44 km away.

2.3 | Data analyses

Every 10 s of acoustic data was used to determine power spectral densities (PSDs). Broadband sound pressure levels (SPLs;

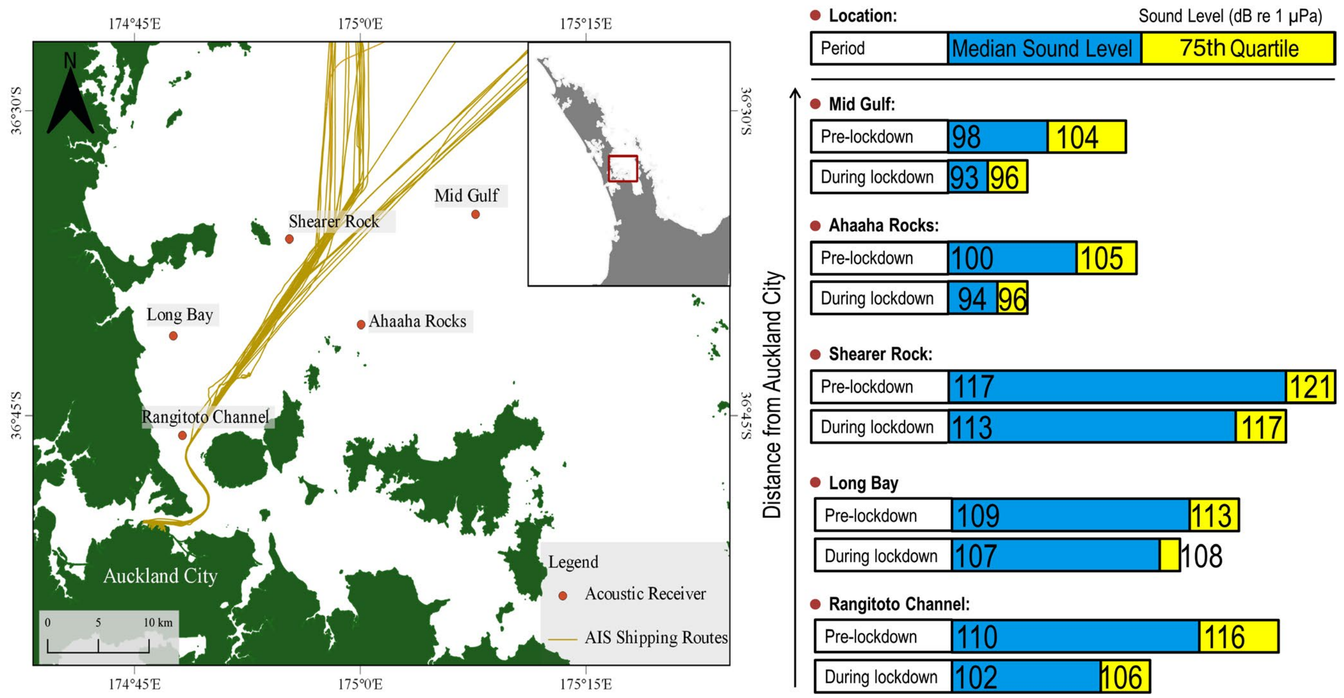

FIGURE 1 Map of the Hauraki Gulf Marine Park showing the location of the sea-mounted acoustic recording stations and corresponding median sound pressure levels (SPLs) measured before and during the lockdown (7 weeks for both periods). The blue bars represent the median SPL (dB re 1 μPa) measured during daylight hours, whereas the yellow bars represent the 75th quartile for the median [Colour figure can be viewed at wileyonlinelibrary.com]

10 Hz–24 kHz) were calculated as an average over each 2 min recording using 1 s Hamming windows and 50% overlap. This generated a single SPL value every 10 min (due to the 2 min recording for every 10-min duty cycle); 6 samples per hour and 144 samples per day. To control for increased ambient noise resulting from elevated wind speed, only acoustic data recorded during the hours of wind speed below 18.5 km/h, that is, 10 knots, were selected for statistical analyses, comprising 45% of the total data set. These missing data points occurred randomly across time. Daily median SPLs were extracted from this delimited data set for each sampling site and pooled into two periods, pre-lockdown (i.e. 1 February to 25 March 2020) and during the lockdown (i.e. 26 March–8 May 2020), which were then compared with Mann–Whitney tests.

Vessel activity at each site was determined from the 2-min recordings over each 24 h period (from 00:00 to 23:59 h) using a vessel noise detector, which used a convoluted neural network (CNN) with nine neural layers. The CNN was trained on 10,000 PSD spectrograms of vessel noise from archived data in MATLAB, with a validation accuracy of 96% after 8 epochs. The validation was performed on a separate dataset containing 5,165 different spectrograms. The detector did not classify the type of vessel, instead identified predominately the presence of harmonic tones and Lloyd mirror patterns. Every detection was examined and confirmed by visually examining spectrograms. Over half of all recordings were also manually reviewed to confirm the reliability of the acoustic detection algorithms and to further ensure all vessel noise signatures were detected. The proportion of 2-min recordings that contained vessel noise over the total number of recordings in a single 24 h period was calculated to provide a measure of vessel activity in the vicinity of the recording site. The relationship between measured vessel activity per day and median SPL per day (the response variable) at each site were evaluated with generalized linear models (GLM), after confirming that the required assumptions were met, including independence.

Bottlenose dolphins (*Tursiops truncatus*) and bigeyes fish (herein called bigeyes, *Pempheris adspersa*) are both commonly found in the Hauraki Gulf, maintain social groupings via acoustic communication and have well documented acoustic source levels and hearing thresholds. This enabled the calculation of communication range. The communication range is the maximum distance from a vocalizing animal at which a conspecific listener could detect and perceive the source animal's signal (Clark et al., 2009). Whistles are an important component of the bottlenose dolphin vocal repertoire, playing an important role in dolphin communication and social dynamics (Au & Hastings, 2008; Frankel et al., 2014). Whistles are pervasive and omnidirectional signals, unlike the much higher frequency and highly directional echolocation clicks or burst pulses commonly used by many dolphin species (Au & Hastings, 2008). In contrast, the low-frequency pop sounds from bigeyes are considered a model acoustic signal for fish due to their limited frequency range and source levels (Putland et al., 2018; Radford et al., 2015). To calculate communication ranges for dolphin whistles and fish calls, a simplified sonar equation (Clark et al., 2009), that has previously been used within the Hauraki Gulf, was applied to the data (Putland et al., 2018). Key assumptions for the communication range calculations were as follows: (1) the signal was ambient noise limited (as determined by the

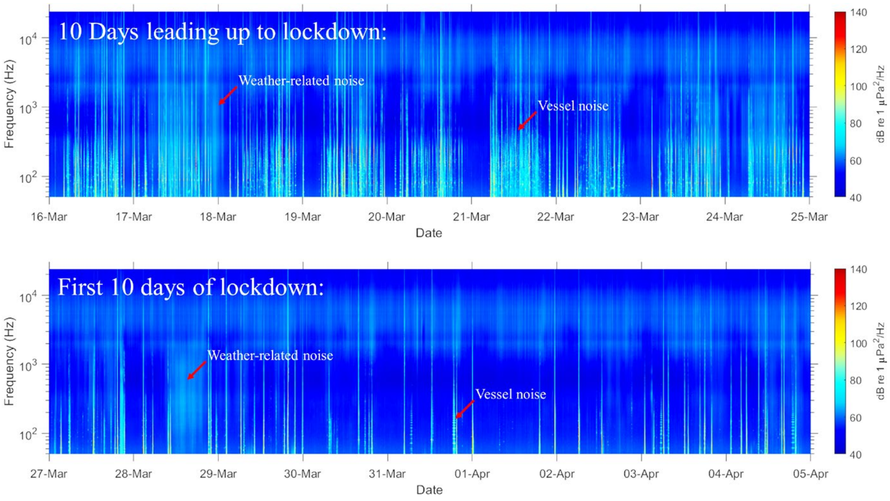

FIGURE 2 Spectrograms before and during the lockdown within the Rangitoto Channel. The diurnal presence of vessels is particularly noticeable below 1 kHz before the lockdown [Colour figure can be viewed at wileyonlinelibrary.com]

audiogram values for bottlenose dolphins and bigeyes being lower than the ambient sound levels in the same critical bandwidths within the Hauraki Gulf); (2) no masking release mechanisms occurred and (3) both the dolphin's or fish's hearing and the propagation of their calls were omnidirectional. Masking release mechanisms are strategies used by animals to counteract naturally occurring maskers, such as waves or conspecific or heterospecific choruses (Pine et al., 2020). They can include increasing the amplitude of their calls (Lombard effect), changing the spectral characteristics of the call, reduce the spectral overlap with the masker or changing the timing of their calls (Erbe et al., 2016; Radford et al., 2014).

The signal excess equation used to calculate the communication range was

$$\mathrm{SE} = \mathrm{SL} - N\log 10(R) - \mathrm{MSL} - \mathrm{DT},$$

where signal excess, SE, equals zero at the limited range of detection, SL is the source level of the dolphin's whistle (set at the median level of 138.2 dB re 1 µPa @ 1 m, Frankel et al., 2014) or fish's call (116 dB re 1 µPa @ 1 m, Radford et al., 2015), N is the propagation coefficient over some distance R, MSL is the hourly mean ambient SPL and DT was the detection threshold (set at 10 dB, following recent research on dolphin communication space in the Hauraki Gulf, Putland et al., 2018). The bandwidth of a dolphin's whistle was set between 268 and 18,115 Hz (Frankel et al., 2014), whereas the bandwidth of fish calls was set between 90 and 700 Hz (Radford et al., 2015). The corresponding MSL for those same bandwidths were calculated, after adjusting for half a critical bandwidth either side of the whistle or call frequency limits. The frequency cut-offs for the MSL calculations were based on critical ratio curves (Erbe et al., 2016) for the dolphin whistles, but for the fish calls, the critical bandwidths were based on previous measures (Hawkins & Chapman, 1975). To investigate the relationships between the dolphin's or fish's communication ranges and daytime vessel activity, the MSL values were calculated for the daytime only when wind speeds were below 18.5 km/h. The propagation coefficient, N, determines the rate of acoustic attenuation of the source signal and was calculated by curve-fitting the modelled propagation loss of each third or full octave centre frequency (represented by the average of three frequencies within each octave band) within the dolphin whistle's (i.e. 268 and 18,115 Hz) or fish call's (i.e. 90 and 700 Hz) bandwidth, respectively. The propagation models used for this were a combination of the fully-range-dependent parabolic equation method (RAMGeo [for frequencies below 1.6 kHz]) and ray/Gaussian beam tracing (Bellhop [for frequencies above 1.6 kHz]), for 72 radials from the position of the hydrophone (Pine et al., 2019). Because Bellhop is based on Snell's law, it is applicable if a signal's wavelength is much shorter than the layer within which it is propagating. It was for this reason that the 1.6 kHz cut-off was used for the switch from PE to Bellhop models. Bathymetry data were obtained from NIWA, and the seafloor sediment was set as homogenous soft sediment of silt and sand. Sound speed profiles for the summer (January–February) and autumn (March–May) months were calculated from temperature and salinity data obtained from the Waikato Regional Council.

The communication ranges for bottlenose dolphins and bigeyes were calculated for each hour when wind speeds were below 18.5 km/h for two of the sites. The Rangitoto Channel is the main shipping channel into the Ports of Auckland City and was the shallowest sampling site at 15 m depth, whereas the Ahaaha Rocks is an important site for recreational and tourism activities, such as fishing and cruising with deeper water (35 m). The hourly communication ranges for each species were then averaged over each daytime period (sunrise to sunset, Beauducel, 2020) and the daily median communication ranges compared with corresponding measures of daily daytime SPLs (daily SPLs) and vessel activity using GLM, after confirming that the required assumptions were met.

3 | RESULTS

3.1 | Effects of the lockdown on the overall SPLs

The lockdown had an immediate and significant effect on the underwater soundscape at all sites within the HGMP, particularly at frequencies below 1 kHz (Figure 2). For example, daily SPLs below

100 Hz dropped from 100 to 88 dB re 1 μPa and for 100–1000 Hz from 103 to 88 dB re 1 μPa. In the weeks leading up to lockdown, hourly SPLs below 100 Hz ranged between 83 and 155 dB re 1 μPa, which decreased to between 78 and 120 dB re 1 μPa during the lockdown. Between 100 and 1000 Hz, hourly SPLs ranged between 84 and 141 dB re 1 μPa pre-lockdown but between 80 and 122 dB re 1 μPa during the lockdown.

The most noticeable effects of the lockdown were as follows: (1) near-constant presence of vessel noise recorded before the lockdown (during daylight hours) suddenly dropped off and (2) variation in SPLs were substantially reduced, indicating markedly lower number of vessels passing by the hydrophones. As a result, median (±75% quartile) SPLs decreased by 8 dB (from 110 ± 6 dB to 102 ± 4 dB re 1 μPa (p < .001)) within the Rangitoto Channel (a busy thoroughfare); approximately 6 dB off the Ahaaha Rocks (from 100 ± 4 dB to 94 ± 2 dB re 1 μPa (p < .001)) and in the mid-Gulf (from 98 ± 6 dB to 92 ± 3 dB re 1 μPa (p < .001)); and 4 dB (from 117 ± 4 dB to 113 ± 3 dB re 1 μPa (p < .001)) off Shearer Rock (Figure 1). The decrease in noise levels were immediate, with median SPLs down by between 8 dB (Rangitoto Channel) and 10 dB (the mid-Gulf) on the first day of lockdown (26 March 2020).

3.2 | Effects of the lockdown on vessel activity

Due to New Zealand's strict lockdown measures for non-essential vessels, vessel activity significantly decreased. For example, on 25 March 2020, vessel noise within the Rangitoto Channel was recorded 63% of the time, decreasing to 34% on the first day of lockdown, and to just 8% after 5 days, at which point contributions were exclusively from essential commercial shipping activity. There was a statistically significant relationship identified between the decline in the presence of vessel noise per day and the median SPL per day, after controlling for wind speeds (GLM: Rangitoto Channel R^2 = .75, p < .001; Ahaaha Rocks R^2 = .71, p < .001; Figure 3). For example, for every 10% increase in vessel noise presence during the day, the daily SPLs increased by approximately 2 dB within the Rangitoto Channel, and the Ahaaha Rocks (Figure 3).

3.3 | Effects of the lockdown on dolphin and fish communication range

The calculated communication range for dolphins and fish significantly increased during the lockdown (Figure 4), and this effect was greater at the sites furthest from the city. For example, the maximum median range within which dolphins were estimated to be able to communicate was approximately 400 m within the Rangitoto Channel prior to lockdown, increasing to 565 m during the first week of lockdown. For fish, daily communication ranges increased from just a few meters to 155 m after the lockdown (Figure 4). At the Ahaaha Rocks, dolphin communication ranges increased from 2.9 km to nearly 4 km and for fish, from 4 to 70 m. Statistical analyses of the median communication ranges and vessel noise presence revealed a significant relationship for both dolphins (GLM: R^2 = .77, p < .001 [Rangitoto Channel]; R^2 = .71, p < .001 [Ahaaha Rocks]) and fish (GLM: R^2 = .81, p < .001 [Rangitoto Channel]; R^2 = .80, p < .001 [Ahaaha Rocks]). After controlling for wind speeds, every 10% increase in the daily presence of vessel noise equated to a 47 m loss in communication range for dolphins within the Rangitoto Channel and 519 m loss around the Ahaaha Rocks. Fish communication ranges decreased 18 or 13 m within the Rangitoto Channel or off the Ahaaha Rocks, respectively.

4 | DISCUSSION

Although the effects of noise pollution and the role of auditory masking on animal behaviour have been well studied (Shannon et al., 2016), never has it been possible to investigate the reverse in the field. That is, what happens to ambient sound levels and communication ranges when vessel traffic decreases to exceptionally low volumes. The COVID-19 lockdown in New Zealand provided a means to understand the effects of small boat traffic (because commercial shipping continued during the lockdown, although at a reduced level) on shallow water noise levels near a busy metropolitan centre through the collection of baseline data with very little anthropogenic noise. These data showed that ambient noise levels dropped 2 dB for every 10% fall in daily vessel noise presence, equating to tens of meters in expected communication ranges being gained by

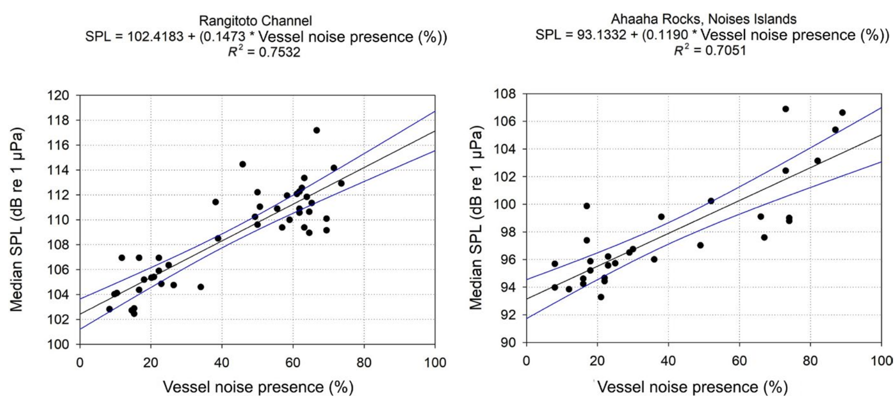

FIGURE 3 Relationships between median sound pressure level (SPL) per day and the daily presence of vessel noise in the ambient soundscape at the shallower Rangitoto Channel site and deeper site at the Ahaaha Rocks [Colour figure can be viewed at wileyonlinelibrary.com]

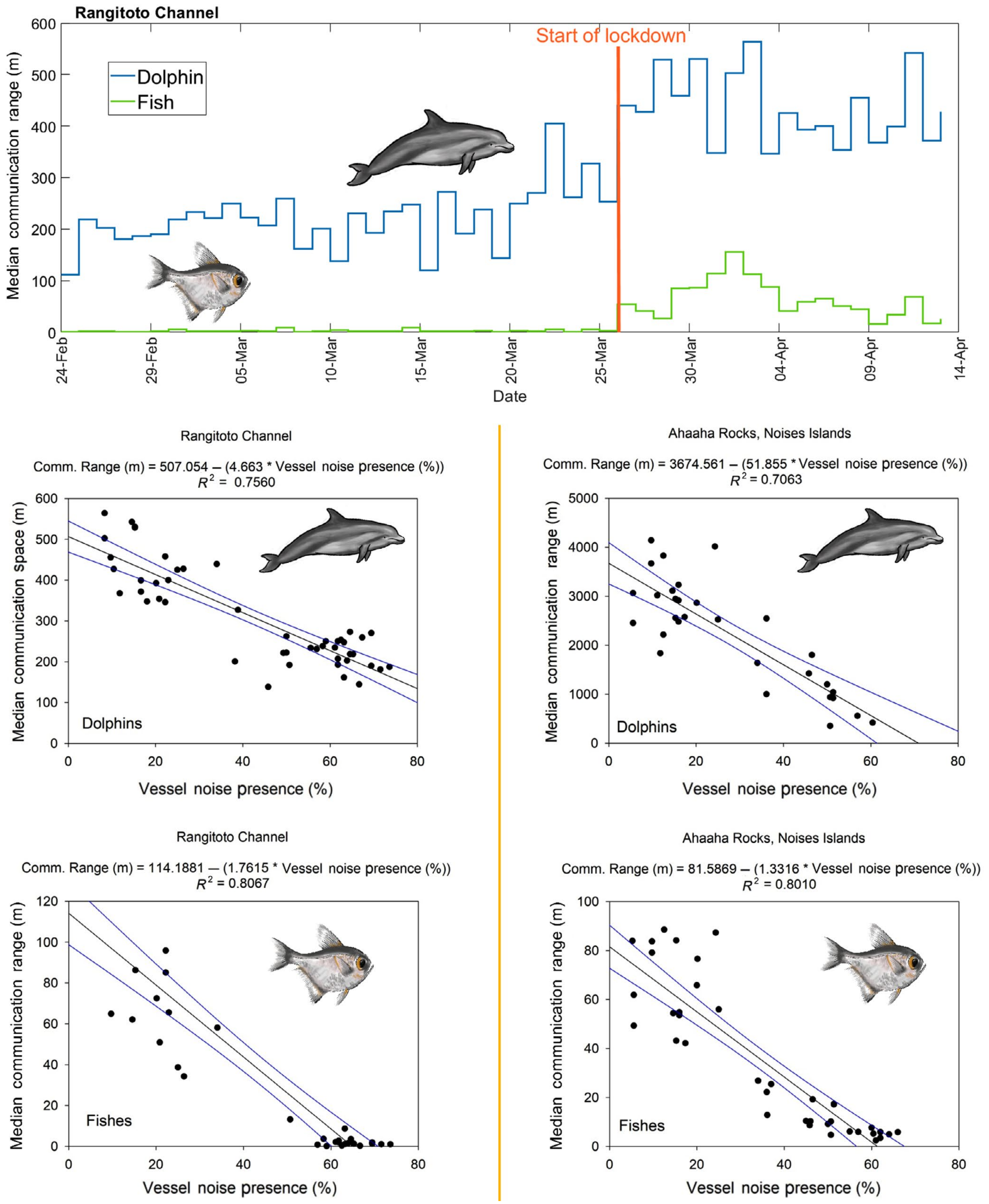

FIGURE 4 Plots showing the effects of vessel noise presence per day (%) on the estimated communication ranges (m) for dolphins and fishes. The stairs plot at the top shows the median communication ranges in dolphins and fishes in the days leading up to, and during, the lockdown. The scatter plots show the relationship between the vessel noise presence per day (%) and corresponding median communication ranges in dolphins and fishes [Colour figure can be viewed at wileyonlinelibrary.com]

fish and hundreds or thousands of meters for dolphins in shallow (<20 m) or deeper (<50 m) water, respectively.

The data collected during the lockdown confirm that vessel noise is likely a key anthropogenic noise source contributing to ambient sound levels within the HGMP. After the lockdown, overall ambient sound levels fell up to 8 dB re 1 μPa over the first 12 h and up to 10 dB re 1 μPa over the entire lockdown period. The proportional presence of vessel noise per day was calculated as the proxy for vessel activity because (1) vessels operating in the area are directly related to the presence of vessel noise and (2) masking in marine animals is related to vessel noise emission rather than the number of vessels operating. The counting of multiple vessels at the same time (since overlapping noise signatures from two or more vessels were not differentiated) or distant/proximate vessels impacting the rate at which ambient sound levels changed in response to vessel activity were controlled for using multiple sites around the inner HGMP of differing depths and wind exposures. The resulting 2 dB change in ambient levels for every 10% rise/fall in vessel activity was seen at both the shallow and deeper sites. Direct translation of our findings to other areas should be carried out carefully, especially if no local data are available and particularly in narrower waterways than those in this study (such as fjords) where vessels would operate in closer proximity to each other and at consistently closer ranges to the hydrophones.

The relationship between communication ranges and vessel activity levels, in contrast, did show some site-dependence, with the bigger gains in communication ranges occurring at the deeper and more exposed sites (i.e. further from Auckland City). Those deeper and more exposed sites experienced greater SPL decreases during the lockdown than the shallower sites due to more distant vessels being recorded at the hydrophone (because low-frequency vessel noise propagates further in deeper water). Therefore, the difference in vessel noise being detected at the deeper sites after the lockdown began was greater than at the shallower sites, meaning the overall drop in SPLs were higher.

There is a mounting body of evidence showing vessel noise to be highly invasive and audible to nearly all marine mammals (Erbe et al., 2016) and fishes (Popper et al., 2014). Smaller vessels, particularly recreational boats, can present a substantial threat in the marine environment in some areas as an unregulated noise source with higher interaction rates with marine animals than any other source (Correa et al., 2019). Furthermore, the sheer volume of recreational boat traffic can dilute the mitigating effect of their transient nature (McWhinnie et al., 2017). Assessing the effects of these vessel movements on the marine environment has become a management challenge. The lockdown measures imposed in New Zealand during the busy summer/fall boating season provided the fundamental data needed to statistically test relationships between vessel traffic and noise levels, and the effects of cumulative vessel noise on the overall communication range of dolphins and fish. Furthermore, the extended period for which lockdown occurred (7 weeks) meant that an extensive data set was obtained, providing superior baseline values compared with previous recordings and estimates. This event provided an unprecedented chance to rigorously assess some key parameters, including relating the number of vessels passing through an area required to raise the ambient noise floor of that area by a single decibel (i.e. cumulative noise) and relating vessel noise exposure to impacts on the communication range in marine animals.

The unprecedented low SPLs recorded during the lockdown were particularly interesting because of the known influence vessel noise can have on the ability of marine animals to communicate (Erbe et al., 2016; Hawkins & Picciulin, 2019). Masking of marine animals' acoustic communication signals by small vessel noise is a key research question after being somewhat neglected compared with the attention given to noise from commercial shipping (Erbe et al., 2019). For many coastal areas, small vessels are likely to be the most prevalent and ongoing source of masking noise in shallow waters. Previous studies have investigated reductions in animal communication ranges from individual commercial or small vessels, including within the HGMP, with small vessels raising ambient noise levels at least 47 dB re 1 μPa (Li et al., 2015) or as much as 75 dB re 1 μPa nearer the passing vessel (Pine et al., 2016). However, the cumulative effect of many individual vessels passing during daylight hours on the overall communication range has not been measured before, as vessel activity has not dropped low enough to obtain true baseline data. The New Zealand lockdown provided a unique opportunity to obtain these baseline data as the daily presence of general vessel noise decreased to 8%. During the lockdown, there was significant increase in dolphin and fish communication ranges, hundreds of meters to several kilometers for dolphins and tens of meters to hundreds of meters for fish. Overall, the daily communication range more than doubled after the lockdown began, and for every 10% decrease in daily vessel noise presence, the communication range increased by between 47 and 519 m for dolphins, or 13 and 18 m for fish, respectively.

The expected benefits of the reduced interference by boat noise are an improved ability for marine animals to communicate and maintain social cohesion over longer distances, including when foraging, and improving their perception of their environment and associated threats—most likely resulting in lower stress levels (Rolland et al., 2012). Although the first two benefits are more intuitive, lower stress levels occur because anthropogenic noise (including continuous noise, such as small vessel noise) is a well-known stressor in marine mammals (Nowacek et al., 2007; Richardson et al., 1995; Rolland et al., 2012; Wright et al., 2007) and fishes (Hawkins et al., 2020; Hawkins & Popper, 2017; Popper & Hawkins, 2019; Slabbekoorn et al., 2010). For example, North Atlantic right whales (*Eubalaena glacialis*) showed lower baseline levels of glucocorticoids in faecal samples following a 6 dB reduction in ambient noise from reduced vessel activity after the 9/11 terrorist attacks in the United States of America (Rolland et al., 2012). Yangtze finless porpoises (*Neophocaena asiaeorientalis asiaeorientalis*) had higher serum cortisol levels in areas with high vessel activity than conspecifics in areas without vessels (Nabi et al., 2018). Noise-induced stress has also been seen in coral reef fish (Mills et al., 2020), temperate kelp fish (Nichols et al., 2015), European seabass (Spiga et al., 2017) and freshwater fishes (Smith et al., 2004). With sustained decreases in vessel activity due to various lockdowns around the world, the physiological changes in wild fishes and marine mammals (since much research, particularly on fishes, are in captive environments) in response to lower vessel presence would be of particular interest.

5 | CONCLUSIONS

The COVID-19 lockdown measures in New Zealand put a stop to all non-essential vessels operating, bringing a high degree of masking relief for marine life. The dramatic cessation of human activity on the water provided new baseline data on ambient sound levels due to very low vessel activity, revealing the measured cumulative effect that vessel noise has on the ambient soundscape and masking in fish and dolphins. The key advantage of these new data is that they provide strong empirical evidence that small vessels, when in sufficient numbers/presence, directly influence ambient sound levels and are not an acute noise source with limited impact as sometimes believed by regulators. The data also, for the first time, demonstrate how small vessels are already contributing to ambient sound levels in ecologically important areas that are near busy metropolitan centres.

ACKNOWLEDGEMENT

We thank Ryun Madenokoji, Olivier Ghysel, Dr. Keith Pine, Oliver Trottier and Jon Styles for their assistance in the field.

CONFLICT OF INTEREST

The authors declare no competing interests.

AUTHOR CONTRIBUTION

MKP, LW and CAR designed the study, conducted the field work and analysed the data. LM, AS, FJ and CAR provided additional data. All authors contributed to the interpretation of the data and preparing the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Matthew K. Pine https://orcid.org/0000-0002-7289-7115
Louise Wilson https://orcid.org/0000-0002-1970-2710
Andrew G. Jeffs https://orcid.org/0000-0002-8504-1949
Francis Juanes https://orcid.org/0000-0001-7397-0014
Craig A. Radford https://orcid.org/0000-0001-7949-9497

REFERENCES

Andrew, R. K., Howe, B. M., & Mercer, J. A. (2011). Long-time trends in ship traffic noise for four sites off the North American West Coast. *The Journal of the Acoustical Society of America*, *129*(2), 642–651. https://doi.org/10.1121/1.3518770

Au, W. W. L., & Hastings, M. C. (2008). *Principles of marine bioacoustics*. Springer.

Bates, A. E., Primack, R. B.; PAN-Environment Working Group, & Duarte, C. M. (2021). Global COVID-19 lockdown highlights humans as both threats and custodians of the environment. *Biological Conservation*, 109175. https://doi.org/10.1016/j.biocon.2021.109175

Bates, A. E., Primack, R. B., Moraga, P., & Duarte, C. M. (2020). COVID-19 pandemic and associated lockdown as a “Global Human Confinement Experiment” to investigate biodiversity conservation. *Biological Conservation*, *248*. https://doi.org/10.1016/j.biocon.2020.108665

Beauducel, F. (2020). *SUNRISE: Sunrise and sunset times*. Retrieved from https://www.mathworks.com/matlabcentral/fileexchange/64692-sunrise-sunrise-and-sunset-times

Beca. (2012). *Auckland recreational boating study*. Report for Auckland Council, Auckland, p. 40.

Bennett, N. J., Finkbeiner, E. M., Ban, N. C., Belhabib, D., Jupiter, S. D., Kittinger, J. N., Mangubhai, S., Scholtens, J., Gill, D., & Christie, P. (2020). The COVID-19 pandemic, small-scale fisheries and coastal fishing communities. *Coastal Management*, *48*(4), 336–347. https://doi.org/10.1080/08920753.2020.1766937

Clark, C. W., Ellison, W. T., Southall, B. L., Hatch, L., Van Parijs, S. M., Frankel, A., & Ponirakis, D. (2009). Acoustic masking in marine ecosystems: Intuitions, analysis, and implication. *Marine Ecology Progress Series*, *395*, 201–222. https://doi.org/10.3354/meps08402

Cominelli, S., Devillers, R., Yurk, H., MacGillivray, A., McWhinnie, L., & Canessa, R. (2018). Noise exposure from commercial shipping for the southern resident killer whale population. *Marine Pollution Bulletin*, *136*, 177–200. https://doi.org/10.1016/j.marpolbul.2018.08.050

Correa, J. M. G., Bayle Sempere, J.-T., Juanes, F., Rountree, R., Ruíz, J. F., & Ramis, J. (2019). Recreational boat traffic effects on fish assemblages: First evidence of detrimental consequences at regulated mooring zones in sensitive marine areas detected by passive acoustics. *Ocean & Coastal Management*, *168*, 22–34. https://doi.org/10.1016/j.ocecoaman.2018.10.027

Dolman, S. J., & Jasny, M. (2015). Evolution of marine noise pollution management. *Aquatic Mammals*, *41*(4), 357–374. https://doi.org/10.1578/AM.41.4.2015.357

Erbe, C., Marley, S. A., Schoeman, R. P., Smith, J. N., Trigg, L. E., & Embling, C. B. (2019). The effects of ship noise on marine mammals—A review. *Frontiers in Marine Science*, *6*, 606. https://doi.org/10.3389/fmars.2019.00606

Erbe, C., Reichmuth, C., Cunningham, K., Lucke, K., & Dooling, R. (2016). Communication masking in marine mammals: A review and research strategy. *Marine Pollution Bulletin*, *103*(1), 15–38. https://doi.org/10.1016/j.marpolbul.2015.12.007

Farcas, A., Powell, C. F., Brookes, K. L., & Merchant, N. D. (2020). Validated shipping noise maps of the Northeast Atlantic. *Science of the Total Environment*, *735*, https://doi.org/10.1016/j.scitotenv.2020.139509

Frankel, A. S., Zeddies, D., Simard, P., & Mann, D. (2014). Whistle source levels of free-ranging bottlenose dolphins and Atlantic spotted dolphins in the Gulf of Mexico. *The Journal of the Acoustical Society of America*, *135*(3), 1624–1631. https://doi.org/10.1121/1.4863304

Frisk, G. V. (2012). Noiseonomics: The relationship between ambient noise levels in the sea and global economic trends. *Scientific Reports*, *2*(1), 437. https://doi.org/10.1038/srep00437

Hauraki Gulf Forum. (2014). *State of our Gulf—Tikapa Moana*. Hauraki Gulf state of the environment report.

Hawkins, A. D., & Chapman, C. J. (1975). Masked auditory thresholds in the cod, *Gadus morhua* L. *Journal of Comparative Physiology*, *103*(2), 209–226. https://doi.org/10.1007/BF00617122

Hawkins, A. D., Johnson, C., & Popper, A. N. (2020). How to set sound exposure criteria for fishes. *The Journal of the*

Acoustical Society of America, *147*(3), 1762–1777. https://doi.org/10.1121/10.0000907
Hawkins, A. D., & Picciulin, M. (2019). The importance of underwater sounds to gadoid fishes. *The Journal of the Acoustical Society of America*, *146*(5), 3536–3551. https://doi.org/10.1121/1.5134683
Hawkins, A. D., & Popper, A. N. (2014). Assessing the impacts of underwater sounds on fishes and other forms of marine life. *Acoustics Today*, *10*(2), 30–41.
Hawkins, A. D., & Popper, A. N. (2017). A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. *ICES Journal of Marine Science*, *74*(3), 635–651. https://doi.org/10.1093/icesjms/fsw205
Hermannsen, L., Mikkelsen, L., Tougaard, J., Beedholm, K., Johnson, M., & Madsen, P. T. (2019). Recreational vessels without Automatic Identification System (AIS) dominate anthropogenic noise contributions to a shallow water soundscape. *Scientific Reports*, *9*(1), 15477. https://doi.org/10.1038/s41598-019-51222-9
Hildebrand, J. A. (2009). Anthropogenic and natural sources of ambient noise in the ocean. *Marine Ecology Progress Series*, *395*, 5–20. https://doi.org/10.3354/meps08353
Jones, N. (2019). The quest for quieter seas. *Nature*, *568*, 158–161.
Joy, R., Tollit, D., Wood, J., MacGillivray, A., Li, Z., Trounce, K., & Robinson, O. (2019). Potential benefits of vessel slowdowns on endangered southern resident killer whales. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2019.00344
Lecocq, T., Hicks, S. P., Van Noten, K., van Wijk, K., Koelemeijer, P., De Plaen, R. S. M., Massin, F., Hillers, G., Anthony, R. E., Apoloner, M.-T., Arroyo-Solórzano, M., Assink, J. D., Büyükakpınar, P., Cannata, A., Cannavo, F., Carrasco, S., Caudron, C., Chaves, E. J., Cornwell, D. G., … Xiao, H. (2020). Global quieting of high-frequency seismic noise due to COVID-19 pandemic lockdown measures. *Science*, *80*(369), eabd2438. https://doi.org/10.1126/science.abd2438
Li, S., Wu, H., Xu, Y., Peng, C., Fang, L., Lin, M., Xing, L., & Zhang, P. (2015). Mid- to high-frequency noise from high-speed boats and its potential impacts on humpback dolphins. *The Journal of the Acoustical Society of America*, *138*(2), 942–952. https://doi.org/10.1121/1.4927416
Luís, A. R., Couchinho, M. N., & dos Santos, M. E. (2014). Changes in the acoustic behavior of resident bottlenose dolphins near operating vessels. *Marine Mammal Science*, *30*(4), 1417–1426. https://doi.org/10.1111/mms.12125
Mandal, I., & Pal, S. (2020). COVID-19 pandemic persuaded lockdown effects on environment over stone quarrying and crushing areas. *Science of the Total Environment*, *732*. https://doi.org/10.1016/j.scitotenv.2020.139281
McWhinnie, L., Smallshaw, L., Serra-Sogas, N., O'Hara, P. D., & Canessa, R. (2017). The grand challenges in researching marine noise pollution from vessels: A horizon scan for 2017. *Frontiers in Marine Science*. https://doi.org/10.3389/fmars.2017.00031
Mills, S. C., Beldade, R., Henry, L., Laverty, D., Nedelec, S. L., Simpson, S. D., & Radford, A. N. (2020). Hormonal and behavioural effects of motorboat noise on wild coral reef fish. *Environmental Pollution*, *262*, 114250. https://doi.org/10.1016/j.envpol.2020.114250
Mooney, T. A., Di Iorio, L., Lammers, M., Lin, T.-H., Nedelec, S. L., Parsons, M., Radford, C., Urban, E. D., & Stanley, J. (2020). Listening forward: Approaching marine biodiversity assessments using acoustic methods. *Royal Society Open Science*, *7*(8), 201287. https://doi.org/10.1098/rsos.201287
Nabi, G., Hao, Y., McLaughlin, R. W., & Wang, D. (2018). The possible effects of high vessel traffic on the physiological parameters of the critically endangered Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*). *Frontiers in Physiology*. https://doi.org/10.3389/fphys.2018.01665
Nichols, T. A., Anderson, T. W., & Širović, A. (2015). Intermittent noise induces physiological stress in a coastal marine fish. *PLoS One*, *10*(9), 1–13. https://doi.org/10.1371/journal.pone.0139157
Nowacek, D., Thorne, L. H., Johnston, D. W., & Tyack, P. L. (2007). Reponses of cetaceans to anthropogenic noise. *Mammal Review*, *37*(2), 81–115. https://doi.org/10.1111/j.1365-2907.2007.00104.x
Patrício Silva, A. L., Prata, J. C., Walker, T. R., Campos, D., Duarte, A. C., Soares, A. M. V. M., Barcelò, D., & Rocha-Santos, T. (2020). Rethinking and optimising plastic waste management under COVID-19 pandemic: Policy solutions based on redesign and reduction of single-use plastics and personal protective equipment. *Science of the Total Environment*, *742*. https://doi.org/10.1016/j.scitotenv.2020.140565
Peng, C., Zhao, X., & Liu, G. (2015). Noise in the sea and its impacts on marine organisms. *International Journal of Environmental Research and Public Health*, *12*(10), 12304–12323. https://doi.org/10.3390/ijerph121012304
Pine, M. K., Jeffs, A. G., Wang, D., & Radford, C. A. (2016). The potential for vessel noise to mask biologically important sounds within ecologically significant embayments. *Ocean and Coastal Management*, *127*, 63–73. https://doi.org/10.1016/j.ocecoaman.2016.04.007
Pine, M. K., Nikolich, K., Martin, B., Morris, C., & Juanes, F. (2020). Assessing auditory masking for management of underwater anthropogenic noise. *The Journal of the Acoustical Society of America*, *147*(5), 3408–3417. https://doi.org/10.1121/10.0001218
Pine, M. K., Schmitt, P., Culloch, R. M., Lieber, L., & Kregting, L. T. (2019). Providing ecological context to anthropogenic subsea noise: Assessing listening space reductions of marine mammals from tidal energy devices. *Renewable and Sustainable Energy Reviews*, *103*, 49–57. https://doi.org/10.1016/j.rser.2018.12.024
Pine, M. K., Wang, K., & Wang, D. (2017). Fine-scale habitat use in Indo-Pacific humpback dolphins, *Sousa chinensis*, may be more influenced by fish rather than vessels in the Pearl River Estuary, China. *Marine Mammal Science*, *33*(1), 291–312. https://doi.org/10.1111/mms.12366
Popper, A. N., & Hawkins, A. D. (2019). An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. *Journal of Fish Biology*, *94*(5), 692–713. https://doi.org/10.1111/jfb.13948
Popper, A. N., Hawkins, A. D., Fay, R. R., Mann, D. A., Bartol, S., Carlson, T. J., Coombs, S., Ellison, W. T., Gentry, R. L., Halvorsen, M. B., & Løkkeborg, S. (2014). *Sound exposure guidelines for fishes and sea turtles: A technical report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI*. Springer. https://doi.org/10.1007/978-3-319-06659-2
Putland, R. L., Merchant, N. D., Farcas, A., & Radford, C. A. (2018). Vessel noise cuts down communication space for vocalizing fish and marine mammals. *Global Change Biology*, *24*(4), 1708–1721. https://doi.org/10.1111/gcb.13996
Radford, A. N., Kerridge, E., & Simpson, S. D. (2014). Acoustic communication in a noisy world: Can fish compete with anthropogenic noise? *Behavioral Ecology*, *25*(5), 1022–1030. https://doi.org/10.1093/beheco/aru029
Radford, C. A., Ghazali, S., Jeffs, A. G., & Montgomery, J. C. (2015). Vocalisations of the bigeye *Pempheris adspersa*: characteristics, source level and active space. *The Journal of Experimental Biology*, *218*(6), 940–948. https://doi.org/10.1242/jeb.115295
Richardson, W. J., Greene, C. R., Malme, C. I., & Thomson, D. H. (1995). *Marine mammals and noise*. Academic Press.
Rolland, R. M., Parks, S. E., Hunt, K. E., Castellote, M., Corkeron, P. J., Nowacek, D. P., Wasser, S. K., & Kraus, S. D. (2012). Evidence that ship noise increases stress in right whales. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1737), 2363–2368. https://doi.org/10.1098/rspb.2011.2429
Rutz, C., Loretto, M.-C., Bates, A. E., Davidson, S. C., Duarte, C. M., Jetz, W., Johnson, M., Kato, A., Kays, R., Mueller, T., Primack, R. B., Ropert-Coudert, Y., Tucker, M. A., Wikelski, M., & Cagnacci, F. (2020). COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nature Ecology & Evolution*, *4*, 1156–1159. https://doi.org/10.1038/s41559-020-1237-z

Shannon, G., McKenna, M. F., Angeloni, L. M., Crooks, K. R., Fristrup, K. M., Brown, E., Warner, K. A., Nelson, M. D., White, C., Briggs, J., McFarland, S., & Wittemyer, G. (2016). A synthesis of two decades of research documenting the effects of noise on wildlife. *Biological Reviews*, *91*(4), 982–1005. https://doi.org/10.1111/brv.12207

Simmonds, M. P., Dolman, S. J., Jasny, M., Parsons, E. C. M., Weilgart, L., Wright, A. J., & Leaper, R. (2014). Marine noise pollution—Increasing recognition but need for more practical action. *Journal of Ocean Technology*, *9*(1), 71–90.

Sims, P. Q., Hung, S. K., & Würsig, B. (2012). High-speed vessel noises in west Hong Kong waters and their contributions relative to Indo-Pacific humpback dolphins (*Sousa chinensis*). *Journal of Marine Biology*, *2012*, 169103. https://doi.org/10.1155/2012/169103

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., ten Cate, C., & Popper, A. N. (2010). A noisy spring: The impact of globally rising underwater sound levels on fish. *Trends in Ecology and Evolution*, *25*(7), 419–427. https://doi.org/10.1016/j.tree.2010.04.005

Smith, M. E., Kane, A. S., & Popper, A. N. (2004). Noise-induced stress response and hearing loss in goldfish (*Carassius auratus*). *Journal of Experimental Biology*, *207*(3), 427–435. https://doi.org/10.1242/jeb.00755

Spiga, I., Aldred, N., & Caldwell, G. S. (2017). Anthropogenic noise compromises the anti-predator behaviour of the European seabass, *Dicentrarchus labrax* (L.). *Marine Pollution Bulletin*, *122*(1–2), 297–305. https://doi.org/10.1016/j.marpolbul.2017.06.067

Stanley, J. A., Van Parijs, S. M., & Hatch, L. T. (2017). Underwater sound from vessel traffic reduces the effective communication range in Atlantic cod and haddock. *Scientific Reports*, *7*(14633), 1–12. https://doi.org/10.1038/s41598-017-14743-9

Thomson, D. J. M., & Barclay, D. R. (2020). Real-time observations of the impact of COVID-19 on underwater noise. *The Journal of the Acoustical Society of America*, *147*(5), 3390–3396. https://doi.org/10.1121/10.0001271

Weilgart, L. S. (2007). The impacts of anthropogenic ocean noise on cetaceans and implications for management. *Canadian Journal of Zoology*, *85*(11), 1091–1116. https://doi.org/10.1139/Z07-101

Wright, A. J., Aguilar de Soto, N., Baldwin, A. L., Bateson, M., Beale, C. M., Clark, C., Deak, T., Edwards, E. F., Fernández, A., Godinho, A., Hatch, L. T., Kakuschke, A., Lusseau, D., Martineau, D., Romero, M. L., Weilgart, L. S., Wintle, B. A., Notarbartolo-di-Sciara, G., & Martin, V. (2007). Do marine mammals experience stress related to anthropogenic noise? *International Journal of Comparative Psychology*, *20*(4), 274–316. https://doi.org/10.5070/P4202009994

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

How to cite this article: Pine, M. K., Wilson, L., Jeffs, A. G., McWhinnie, L., Juanes, F., Scuderi, A., & Radford, C. A. (2021). A Gulf in lockdown: How an enforced ban on recreational vessels increased dolphin and fish communication ranges. *Global Change Biology*, 27, 4839–4848. https://doi.org/10.1111/gcb.15798