Hauling mitigation for small longline vessels

Final Report

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Executive Summary

Simple haul mitigation devices were trialled on two pelagic longline vessels and one demersal longliner. A combination of real time observations and Go Pro footage was used to collect data on the pelagic longline vessels. Additionally, on the demersal longliner, electronic monitoring video footage collected to monitor seabird captures under MPI project PSB 2019-06 was used to collect data over a longer time period. All data sources were comparable and returned similar results.

During at-sea observations it was apparent that birds consistently followed the vessel using different circular flight patterns depending on the wind direction relative to the vessel. This influenced how easily they could access the area beside the hauling station and what proportion of their time was available for searching for baits. During one pelagic longline trip birds were observed selectively taking sanma baits, in preference to squid, from branchlines in front of the vessel.

Due to low capture and direct interaction rates, it was necessary to use bird attendance in the area around the longline as a proxy for risk. Model results showed that mitigation devices reduced the number of birds moving into the area immediately around the hauling station. On the demersal longliner, retrieving surface floats also reduced bird attendance beside the hauling station.

Data collected in real time allowed for investigation of the influence of additional variables on the numbers of birds moving into the area beside the hauling station. For the models fitted to pelagic longline data, and both pelagic and demersal longline data, higher proportions of squid bait reduced the number of birds entering the area beside the hauling station. The model fitted to demersal longline data showed that higher wind speeds increased the number of birds entering the area beside the hauling station.

Although not selected in the final models, observations of bird behaviour during the haul indicated that wind strength and direction relative to the vessel influenced the ease with which birds could access baited hooks. Exploring these relationships statistically would require larger real time data sets. However, we note that plausible effects of wind direction were apparent in some of the models fitted during the variable-selection process.

The use of EM data allowed for generation of a longer-term data set, and it is recommended that the mitigation employed by the vessel should be routinely recorded when collecting data from video footage, to allow for analysis across larger data sets.

This work shows that simple and cheap hauling mitigation devices can reduce risk to birds during longline hauling with minimal impact on fishing operations. It is recommended that all longline vessels are encouraged to and supported to develop hauling mitigation.

Introduction

Small vessel longline fisheries are a large contributor to bycatch of several of New Zealand's most at-risk seabird species (Richard et al., 2020). Historically most research and development resources have been invested in mitigating captures during line setting. However, a significant portion of interactions between longline vessels and seabirds occur at hauling. On vessels under 28 m, approximately 35% of observed demersal longline captures and 16% of pelagic longline captures were alive (Fishing years 2003-04 – 2017-18, Dragonfly 2021, https://psc.dragonfly.co.nz).

While many of these live captures result in live releases, injuries may be sustained and the long-term fate of the birds is unclear (Richard et al., 2020). Additionally, dehooking and untangling seabirds poses a health and safety risk to crew as well as unnecessary delays to fishing operations. Therefore, it is mutually beneficial to invest in strategies which effectively mitigate against interactions at hauling.

This project continues to develop haul mitigation devices trialled in Goad (2018), and examines the efficacy of utilising video observation to collect interaction data.

Objective

The overall objective of this project is to develop effective and practical options to mitigate the capture of seabirds on haul in small vessel demersal and pelagic longline fisheries.

Methods

At-sea trips

Demersal long line vessel: Ten days were spent at sea over the course of four trips on a snapper target demersal longline vessel (J) fishing from Whitianga. A total of nine lines were set in the dark, and hauled during the morning in the area between Great Mercury Island, Coromandel Peninsula, and Great Barrier Island.

Pelagic longline vessels: Two vessels with different hull designs and deck layouts were used for trials in the pelagic longline fishery. Initially a short trip (two sets) was carried out on vessel T, north of East Cape in August, targeting southern bluefin tuna. Two further trips were undertaken, one on vessel T in January (four sets), north of White Island, targeting yellowfin and bigeye tuna, and swordfish. A third trip, in June (six sets), was conducted on a separate vessel (C), targeting bluefin tuna, south of East Cape. Across the three trips 12 longlines were set during darkness, typically after midnight, and hauled during the afternoon and evening.

All vessels were running tori lines and night setting, and during the haul returned baits and any offal were retained onboard and batch discarded.

Mitigation device design and deployment

Mitigation device designs aimed to be cheap to produce, simple to make, easy to deploy and recover, and have minimal impact on fishing operations, as well as reducing risk to birds.

Demersal longlining

Vessel J was a moderate displacement fibreglass snapper longliner with a fully covered deck. Vessel layout was typical of the inshore longline fleet with a hauling station forward on the starboard side. Both a rail mounted a baffler device and a dangler device supported by a split pole attached under the shelter deck were trialled, three metres aft of the hauling station. (Figure 1).

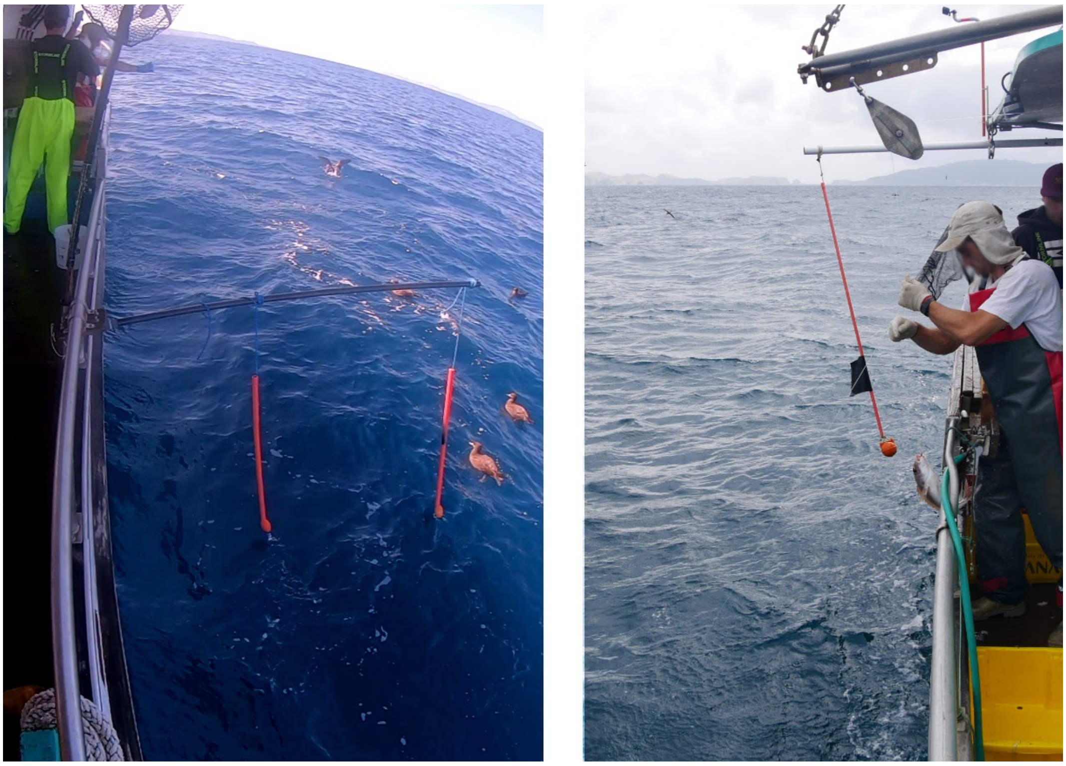


Figure 1. Photograph showing baffler (left, looking forwards) and dangler (right, looking aft) devices trialled on demersal longliner, vessel J. Camera position can be seen at the top right of the second photograph.

Pelagic longlining

Vessel T was a Westcoaster 60 and fitted out in a similar manner to at least six other lighter displacement aluminium and fibreglass pelagic longliners in the New Zealand domestic fleet. The vessel had an open aft deck, so there were limited options for attaching a hauling mitigation device. After discussion with the skipper and crew the decision was made to build a rail mounted mitigation device, fitted behind the hauling station on the port side of the vessel (Figure 2).

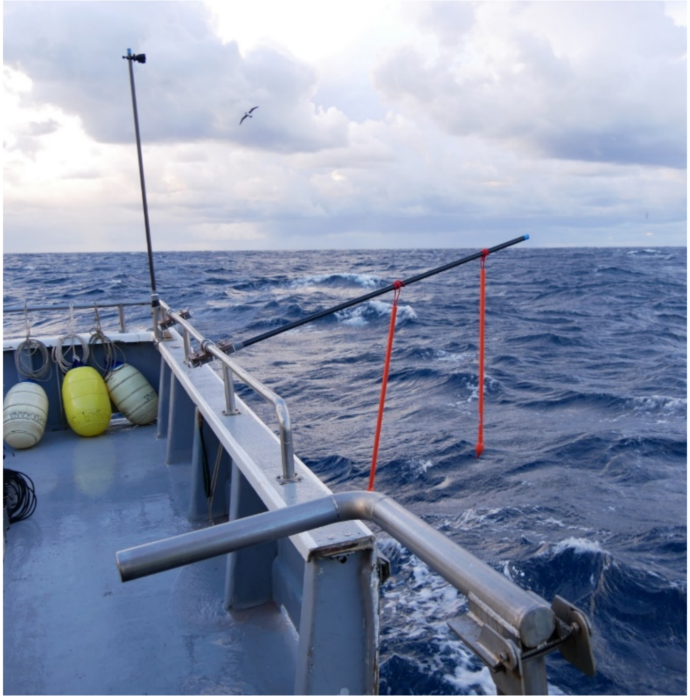


Figure 2. Photograph looking aft from hauling station on Vessel T, showing hauling mitigation device in place and camera position.

Vessel C was a 22 m steel vessel with a full shelter deck which provided a suitable attachment for a 'dangler'-type mitigation device. A horizontal pole suspended a vertical dropper 3.5 m outside of the vessel, aft of the hauling station approximately two metres forward of the transom, on the starboard side of the vessel (Figure 3). A dangler approach was favoured by the skipper as it was thought to be less intrusive to the hauling operation.

Figure 3. Photograph looking aft from in front of the hauling station on Vessel C, showing hauling mitigation device in place. Camera position was astern of the second light on the top of the shelter.

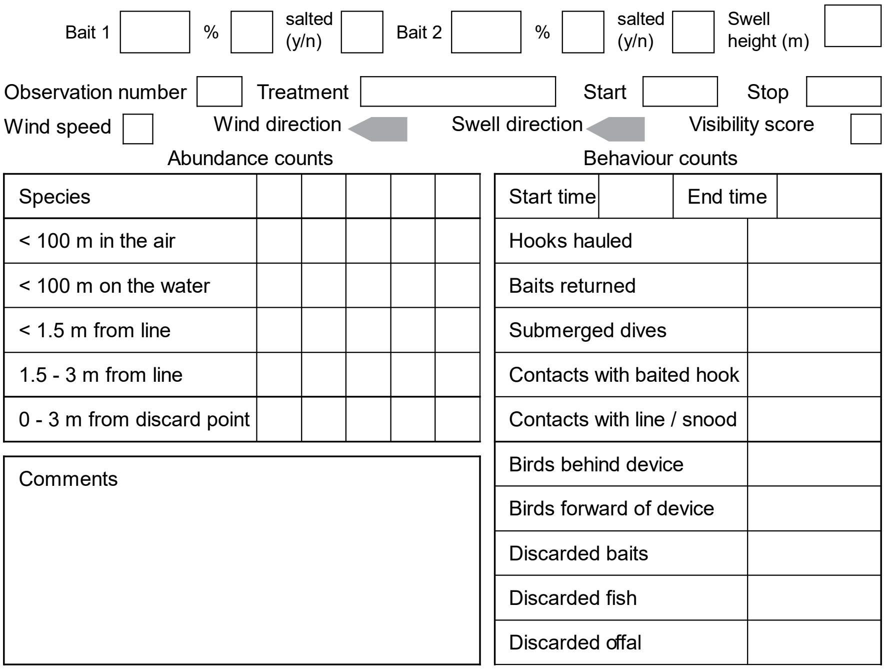
Experimental protocols

Control and use of a mitigation device treatments were alternated within each haul, with typically four (one to six) treatment blocks per line. Treatment blocks were switched at convenient times, aiming to have similar numbers of hooks and observation periods in each block. When hauls ran into darkness block sizes were arranged to have similar numbers of each treatment during both light and dark portions of the haul. Treatments for the first block at the start of the haul were alternated between mitigation and control each day.

Real time counts

Real time seabird observations were conducted during all hauling operations, with protocols alternating between bird abundance counts and observation periods recording bird behaviour.

Abundance counts were split by species or species group and whether birds were in the air or on the water. 'Snapshot' abundances comprised counts of all birds within 100 m radius from the vessel and separate counts of birds within defined areas beside the hauling station (Figures 4 and 5). For graphical presentation species were grouped into large birds (albatrosses and giant petrels) and small birds (all other birds).



Bait 1 ☐ % ☐ salted (y/n) ☐ Bait 2 ☐ % ☐ salted (y/n) ☐ Swell height (m) ☐

Observation number ☐ Treatment ☐ Start ☐ Stop ☐

Wind speed ☐ Wind direction ◀ Swell direction ◀ Visibility score ☐

Abundance counts

Species					
< 100 m in the air					
< 100 m on the water					
< 1.5 m from line					
1.5 - 3 m from line					
0 - 3 m from discard point					

Comments

Behaviour counts

Start time		End time	
Hooks hauled			
Baits returned			
Submerged dives			
Contacts with baited hook			
Contacts with line / snood			
Birds behind device			
Birds forward of device			
Discarded baits			
Discarded fish			
Discarded offal			

Figure 4. Data recording sheet for real time observations.

Behaviour observations were recorded in an area immediately beside the vessel (Figure 5), on the hauling side of the vessel. Separate counts were made of birds moving into the area between the hauling station and mitigation device, and the area astern of the mitigation device. Limiting both areas to a maximum height of three metres off the water was deemed a reasonable approximation of whether birds were attempting to access hooks. On pelagic longline trips birds were not counted if they moved from the forward area into the aft area, as they were moving away from baited hooks and risk, and were never observed to show interest in baits when moving in this direction.

Counts were split by birds in the air and those landing on the water. If a bird moved into the area and landed on the water it was counted only as 'on the water'. Individual birds would move out of the areas, either flying past or being left astern as the vessel moved through the water. When these birds re-entered the observation area they were re-counted, resulting in some individuals being counted multiple times during an observation period. Counts were made of contacts with a bait, hook, or branchline, and of submerged dives.

To consider factors likely to influence the attractiveness of the fishing operation counts were also made of the number of fish discarded, and instances of offal and bait batch discarding were recorded. Bait return rates were also noted but, for most observations, not counted in full. Behaviour observation periods were defined by surface floats, between which hook numbers were consistent within trips when pelagic longlining, and reasonably consistent (approximately 250 hooks) when demersal lining. Treatment blocks typically contained four to six observation periods.

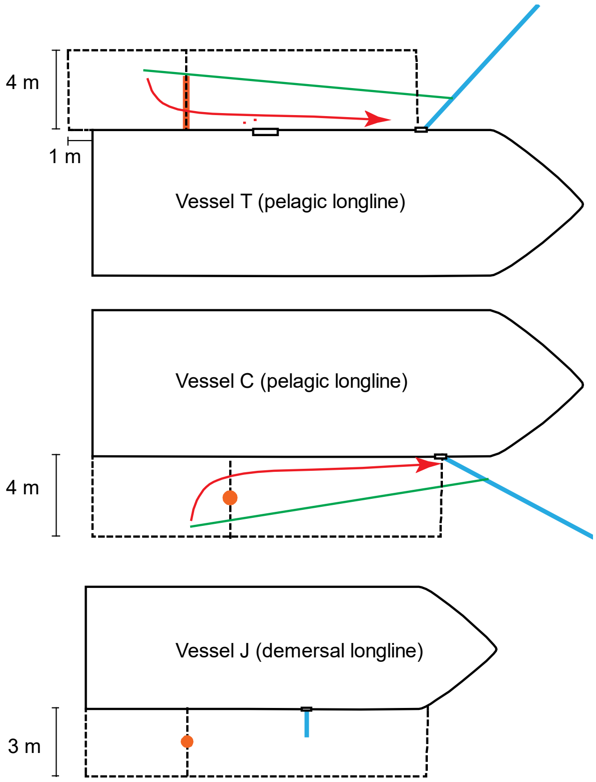


Figure 5. Schematic diagram showing observation boxes. The typical mainline position is shown in blue, and for pelagic longliners, the green line represents a branchline position when the hook breaks the surface, and the red line shows the path the hook takes as it is hauled by hand along the surface. The mitigation device is shown in orange, and the dotted lines represent the observation boxes.

Go Pro video counts

Go Pro Hero 7 black cameras were set up to record wide angle video footage at 1440 p and 60 frames per second. Cameras were positioned on the aft quarter, astern of the hauling station, providing a good view of the area of interest with minimal impact on fishing operations. A mounting height of 2.5 – 3.5 m off the water, with the camera angled forwards 20 degrees from vertical, provided for an adequate field of view while maintaining a practical mounting position.

Bird behaviour count protocols were repeated by watching the video footage, at between 0.5 and 2.8 times normal speed. Translucent masks were used on the viewing monitor to define consistent viewing areas. For pelagic longline trips counts were aggregated at the basket level, and then normalised by the number of hooks hauled (16 hooks on Vessel T and 10 hooks on Vessel C). This allowed for the inclusion of a small number of observations which finished part way through a basket, and a comparison between vessels. For demersal longline trips counts were aggregated every minute, and normalised to counts per minute when comparing with real time observation periods. Data fields from video footage differed slightly from that in real time and were recorded directly into spreadsheets (Tables 1 and 2).

Table 1. Extract from spreadsheet for recording bird behaviour from Go Pro video footage during pelagic longline trips.

basket type (normal or moneymaker)
start time
small birds moving into forward area, landing on the water
small birds moving into aft area, landing on the water
large birds moving into forward area, landing on the water
large birds moving into aft area, landing on the water
count of dives in area
count of dives outside area
count of contacts with branchline / line
small birds moving into forward area, in the air
small birds moving into aft area, in the air
large birds moving into forward area, in the air
large birds moving into aft area, in the air
bait dump (y/n)
count of offal (number fish processed)
hook count

Electronic monitoring (EM) video footage collected on demersal longliner, Vessel J

Access was arranged to video footage collected to monitor seabird captures under MPI project PSB 2019-06. A hemispherical camera was positioned above the hauling table and an online interface (Teem fish, Snapit) was used to review footage with a view outward from the hauling station selected. Footage was watched at 0.5 to 2 times normal speed and a mask was used to ensure the camera view was consistent, and that counts were made in a consistent portion of the image. As per Go Pro video analysis, counts were normalised by time and timestamps were used to isolate real time behaviour observation periods from continuous footage.

Table 2. Extract from spreadsheet for recording bird behaviour from Go Pro and EM footage during demersal longline trips. Note only small birds were observed.

start time
maximum count forward area
maximum count aft area
moving into forward area from aft
moving into forward area from forward
moving into forward area from side
surface float
count of dives
count of contacts

Data analysis

All data analysis was undertaken in R with models fitted using Bayesian Markov chain Monte Carlo (MCMC) methods using the Stan programming language. A negative-binomial likelihood was used to account for overdispersion, with a log-link function. Thin-plate regression splines were used where appropriate to account for non-linear effects of covariates. Models were fitted to data from both pelagic and demersal longlines, with pelagic and demersal longline specific models also fitted to explore for variation between the two fisheries.

Data collected per observation period was normalised by the count of birds within 100 m of the vessel and either the number of hooks hauled (pelagic longlines) or duration (demersal longlines). This excluded observations with no seabirds within 100 m of the vessel, as these do not provide information on the effects of mitigation and other covariates on the rate of seabirds moving into the area forward of the mitigation device..

Covariate selection started from a base model including a 'treatment' effect (i.e. mitigation vs no mitigation) and a random intercept for set id to account for the structure of the dataset, i.e. repeated observations from specific sets. A target species effect was also included in the base model when fitting to observations from pelagic longlines given the observed between-target variation in seabird species assemblages attending the pelagic longliners. The target effect was not required for models fitted exclusively to demersal longlines, as all observed sets were targeting snapper.Candidate covariates explored in the forward-selection procedure included: wind direction relative to the hauling station (12 = within 15° either side of dead ahead, 1 = 15 to 45° from ahead on hauling side, 2 = 45 to 75° from ahead on hauling side, …); swell height (m); swell direction relative to the hauling station (using the same scale as for wind direction); and, the proportion of squid bait. Additionally, when pelagic longline observations were included in the modelled dataset, the candidate covariates also included the proportion of seabirds within 100 m of the vessel that were defined as 'small', i.e. not albatross or giant petrel species. This covariate was not required for models that were fitted exclusively to observations from demersal longlines, as all seabirds within 100 m of the demersal longlines were defined as small.

A detailed description of model structure is provided in Appendix 1.

Results

Trip summaries

Demersal longline

Vessel J worked a typical snapper target fishing schedule, landing every two to three days into Whitianga and fished in the area between Great Mercury Island, Great Barrier Island, and the Coromandel Peninsula. Weather conditions were good with wind strength generally below 15 knots, though rain squalls passed through occasionally. Lines were set in the early morning, around 0330, and hauling commenced after a short soak period and was generally finished by midday. Gear setup aimed to hold most hooks just above the seabed and floats, weights, and weight-float combinations were attached to the line, typically every 25 hooks. Sets one to three were baited with 100% sanma, sets four and five with squid and salted pilchard in the ratio of 4:1, and sets six to nine with squid, barracouta, and pilchard in the ratio of 5:4:1. Sanma was the preferred bait but was not available for later sets and so substituted with squid, barracouta, and pilchard. The pilchard was included as it has a similar oil content to sanma and was thought to provide most scent in the water. However, because pilchard baits were occasionally lost off hooks during the set, despite being salted, it was used only in small quantities and spread along the line. Returned baits were rare and were retained onboard during hauling, and batch discarded during breaks in hauling. Offal discarding was minimal, and occurred only at the end of some hauls.

Seabird abundance was variable between hauls, with maximum numbers of 20 black petrels and 30 flesh-footed shearwaters. Red-billed and black backed gulls were present closer inshore, in smaller numbers though they did dominate some behaviour counts. During hauls three to five, four other vessels were working in the same area and seabird counts were often zero and generally very low. Numbers increased during hauls six to nine as the skipper shifted into deeper water with only one other vessel working nearby.

Pelagic longline

Two sets were undertaken during the first trip by Vessel T, north of Cape Runaway, in reasonable weather conditions: 15 – 25 knots and two to three metre swells. Gear was typical of that used in the winter bluefin fishery: 12 hook baskets with unweighted branchlines and a mixture of squid and sanma baits were employed. Gear was set after dark and hauled in the late morning through the afternoon, finishing before dark. After two sets the poor weather forecast, combined with poor fish prices, resulted in the trip being cut short. The vessel was discarding offal as fish were processed, in batches. Returned baits were retained onboard and discarded in batches during breaks in hauling, typically every one to two hours.

Numbers of birds attending the haul increased from day one to two and increased during each haul. Maximum numbers recorded were 14 black-browed albatross, one great albatross, one giant petrel, 12 grey petrels, 15 grey-faced petrels, and three cape petrels. During hauling birds spent most time in the air astern of the vessel, though at times would settle on the water particularly when feeding on discarded offal. Birds showed little interest in baited hooks and only rarely were birds observed alongside the hauling side of the vessel. Similarly, interest in batch discarded baits was minimal, and birds did not come close to the vessel to feed on discarded baits.

During the second summertime trip on Vessel T lines were set shortly after dark and hauling commenced around 1000 hrs, finishing in daylight, with breaks during the day. Gear setup was alternate 16 hook baskets and 'moneymaker' baskets comprising seven hooks, moneymaker float, and then eight hooks. Bait was again a sanma and squid mix. Tuna catches were reasonable, with 10+ fish per set and few discards. Returned baits were retained and periodically discarded during breaks in hauling, and offal was discarded in batches during processing. Four lines were fished in varying weather conditions with wind strength from 10 to 25 knots and from varying directions relative to the vessel heading.

Flesh-footed shearwaters and black petrels were present around the vessel throughout hauling, typically numbering 30 individuals, with a maximum count of 90. Wandering albatrosses were usually present in ones and twos. Other species included Buller's shearwater, grey-faced petrels and white-capped albatrosses. Flesh-footed shearwaters and black petrels dominated behaviour observations and, at times, were chasing and diving on baited hooks in front of the vessel, with the skipper noting that he could feel them taking sanma baits from the line. One flesh footed shearwater was caught whilst hauling a control section. It was hooked through the wing and released alive. On three occasions a Buller's shearwater was released after landing on deck. No birds were returned dead on the longline. A total of 21 contacts with a branchline or bait and 143 dives were recorded during the second trip.

Vessel C worked a typical winter bluefin fishing schedule, and fished in the vicinity of other vessels for the last four of six sets. Sets started around midnight, with hauling commencing around midday. Gear setup has a repeated sequence of surface float, 10 hooks, surface float, 10 hooks, moneymaker float, 10 hooks. All hooks were baited with squid. Tuna catches were reasonable with 10+ fish a set and surprisingly low shark bycatch, in the order of 20 fish per set. Six lines were fished in typical East Cape conditions with wind speed from 15-35 knots and one day lost to poor weather. Returned baits were retained onboard and batch discarded during breaks in hauling. A mixed assemblage of albatrosses was present throughout hauling, with the black-browed albatross most abundant. Grey petrels and grey-faced petrels were consistently present, generally in small numbers and further from the vessel. No birds were caught; however, a storm petrel was released on four occasions after landing on deck at night. During the trip two contacts with a branchline or bait, and a single dive were recorded.

No birds were observed during any longline setting, on any of the trips.

Mitigation device performance

Demersal longlining

Both a rail mounted 'baffler' type device and a pole mounted 'dangle' type device were trialled during the first two hauls on Vessel J. Both devices altered bird behaviour around the hauling station and reduced access to the area around the line and neither device was qualitatively deemed more effective. The dangler device was chosen for subsequent hauls as it was preferred by the skipper, moved around more and so covered a slightly larger area, and was less intrusive into fishing operations. The dangler did not tangle with the mainline or branchlines, but did tangle with surface float lines on several occasions. These were all untangled swiftly, and did not deter the skipper from using the device. Positioning the device three metres astern of the hauling station was deemed to be as close as possible to the longline, whilst being far enough away to not interfere with normal hauling operations.

Pelagic longlining

The rail mounted 'baffler' device on vessel T was simple to fit and easily adjusted fore and aft along the rail with some vertical adjustment available by tilting the bracket up or down. It was easily and quickly removed from the bracket on the rail during one occasion, when fighting a fish, and on a second occasion when a branchline had to be untangled from around a dropper. The device was moved further aft following haul two on the second trip on the vessel as the average branchline length was longer in the summer fishery. The camera position was also altered to accommodate the new baffler position.

The shelter deck mounted device on vessel C covered a larger area and, because it was mounted overhead, did not interfere with fishing operations and no branchlines were tangled. The horizontal pole and forward and aft stays were left in place all trip and the dangler was recovered using the aft stay when switching treatments. This, unavoidably, resulted in a conservative estimate of the control versus mitigation treatments for the dangler, as birds were observed to alter their direction of flight and to check their approach to the vessel, in response to the horizontal pole alone. Due to the mounting location of the pole, it was not practical to go up on top of the shelter deck to remove it between treatments.

Seabird behaviour

During observations it was apparent that birds consistently followed the vessel using different circular flight patterns depending on the wind direction relative to the vessel. This influenced how easily they could access the area beside the hauling station and what proportion of their time was available for searching for baits. Wind angles forward of the beam, and from the non-hauling side of the vessel, allowed better access for birds, giving them greater access, and larger differences between control and mitigation treatments. Conversely, in wind directions from astern and the hauling side of the vessel access was restricted but mitigation devices caused less obstruction and were less effective (Figure 6).

Demersal longlines were hauled at one to two knots over the ground, and birds were at times able to move towards and stay close to the longline without flying. When wind direction or mitigation reduced direct access to the line birds would, at times, land in front of the vessel and drift/paddle into observation areas. Bait return rates on demersal longlines varied by bait type and were very low, no fish were processed during the haul and whole fish discards were usually live and/or unpalatably large. These factors all resulted in few feeding opportunities.

Hauling speed of pelagic longlines when recovering hooks was typically five knots or higher, and birds were not able to keep up with the vessel and access hooks without flying and landing on the water, targeting a particular hook. The long branchlines and shallow angle of the mainline in front of the vessel resulted in a large window of availability of hooks to diving seabirds (Figure 6).

Bait return rates were high on pelagic longlines, with most hooks without a fish still having a bait on. Bait retention onboard was thorough, however at times crew would jerk branchlines to dislodge baits several metres underwater.

On trip 2 on vessel T flesh-footed shearwaters were observed taking sanma baits from hooks several metres underwater well forward of the vessel. This interaction occurred outside of the area included in behaviour observation counts and was not able to be quantitatively tracked in addition to monitoring the observation areas. The skipper noted that hauling the gear at a steep angle and ensuring that hooks were at fishing depth during breaks in hauling were the only methods for reducing this type of interaction, other than switching to all squid baits. No secondary interactions were observed as albatross abundance was generally low during these hauls (Figure 10).

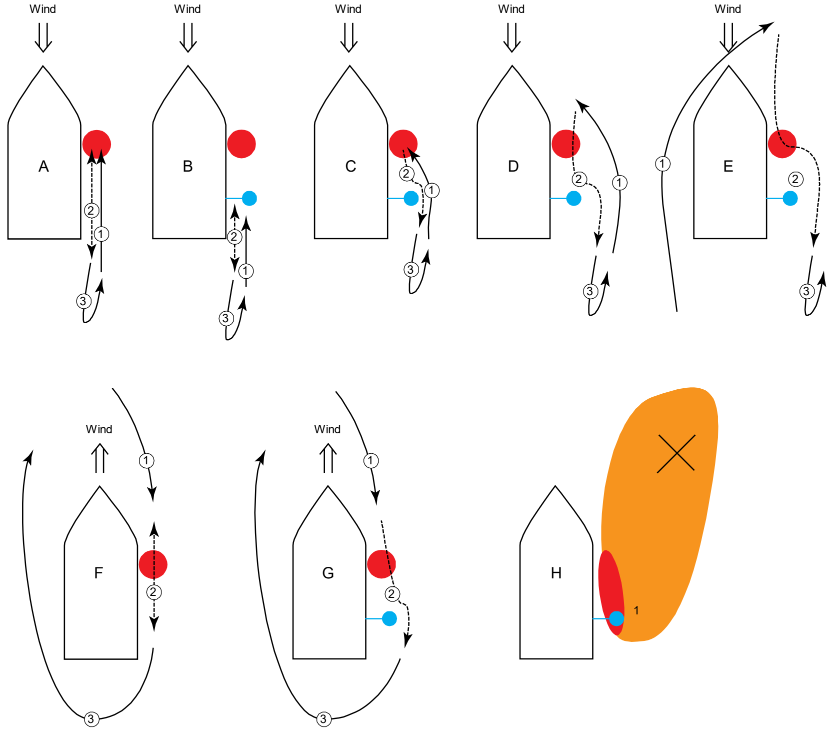


Figure 6. Schematic diagram showing movement of birds in the air (solid lines) and on the water (dotted lines) relative to wind direction and mitigation devices. A-G show the area where hooks are commonly available to birds in red, for a demersal longliner. H shows the larger area of availability on a pelagic longliner for surface-feeding birds (red) and diving birds (orange). The X shows the area in which flesh-footed shearwaters were observed diving on sanma baits.

Behaviour counts

Demersal longlining

Abundance counts often took less than a minute on the demersal longliner, and so behaviour observations covered a greater proportion of, and sometimes the entire, haul. With larger numbers of hooks, and much faster and more continuous and consistent hook hauling than pelagic longlining, time was deemed the easiest and most appropriate measure of exposure to potential risk.

GoPro video footage did not cover quite as large an area as the real time observations due to limitations on camera placement and the need for easy access to clean the lens and to switch batteries (Figure 7). The inbuilt image stabilisation was useful in reducing the effect of vessel movement but this still constantly changed the field of view, especially in poor weather. The use of masks during review, and practice referencing the observation area to fixed points on the vessel, provided the best possible consistency. Judging distance during real time observations was also imperfect but likely more consistent than reviewing video, due to the recorder having better spatial awareness onboard the vessel.

Electronic monitoring footage from the hemispherical lens contained more geometric distortion than the Go Pro camera and had an area missing from a full 360 view (Figure 7). However, observation areas could be consistently defined, relative to the vessel and the field of view, though they did not exactly match those used for real time or Go Pro video footage. Image quality was variable, with dirt on the lens, glare from the water, and fogging at times likely to affect counts. However, all available footage was used, assuming that instances of reduced footage quality were random. Overall, 4045 minute-long observation periods of hauling footage were reviewed from EM footage across 21 days' fishing. As the camera had to be turned on and off manually there were often sections or whole hauls missing from the EM footage, and these outages appeared, and were assumed to be, random.

Neither the Go Pro or EM footage was designed for, or suitable for, assessing total bird abundance around the vessel, due to restricted fields of view.

Observation periods were matched between cameras and real time observations using time stamps, and bar charts and box-whisker plots were produced to summarise bird abundance and behaviour (Figures 9-18). Bird abundance within 100 m followed a similar pattern to count data and real time and camera footage was comparable, with EM footage covering a larger area astern of the vessel. The data was noisy, partially due to the bird behaviour in response to wind direction, however counts of birds in the area forward of the baffler and moving into the area forward of the baffler from astern were lower across real time and both types of camera data (Figure 8).

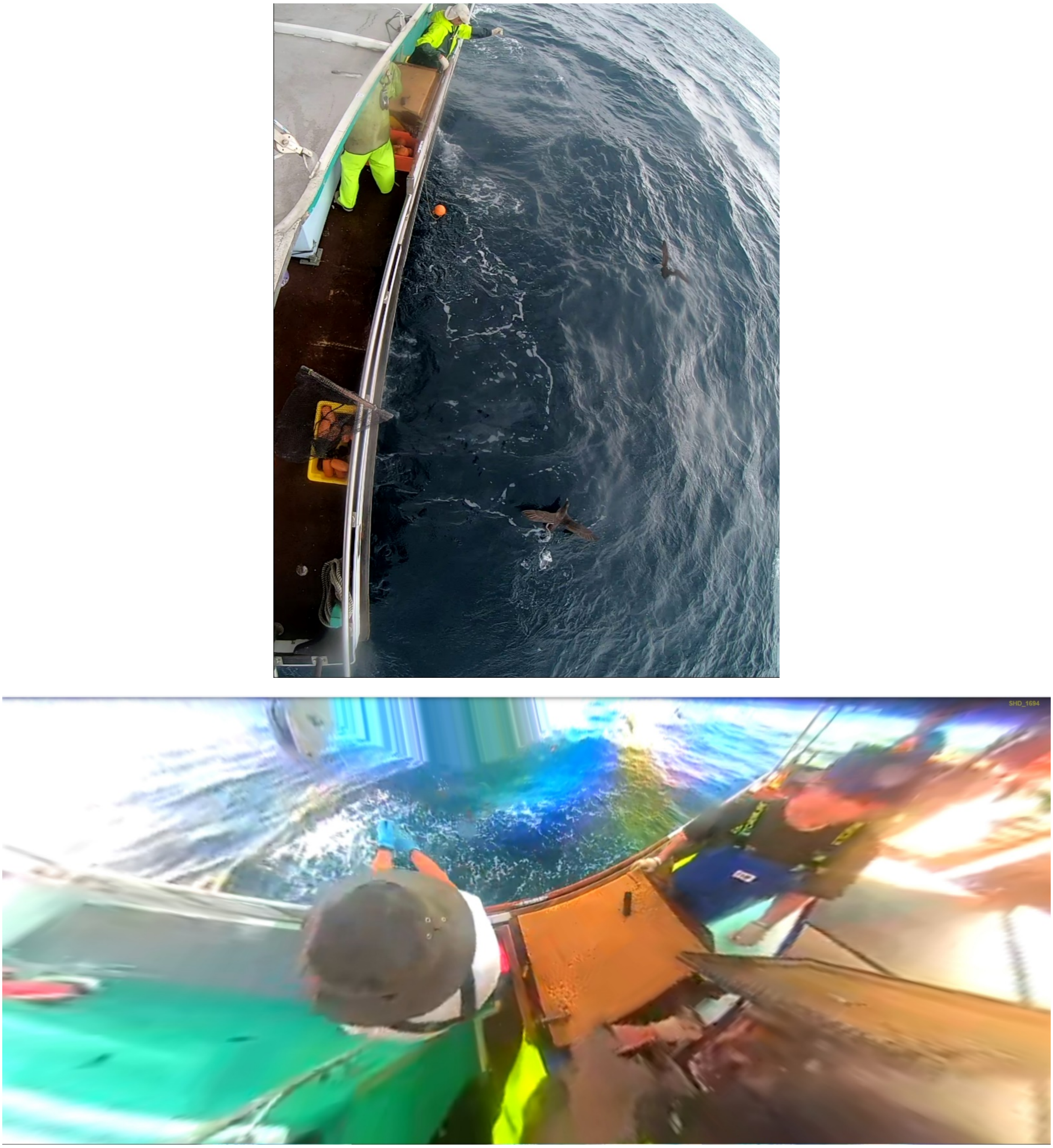


Figure 7. Still photographs taken from GoPro (top) and EM (bottom) video footage.

The extended coverage of EM footage was confounded by gaps in the data and inconsistent application of treatments for recorded hauls. In some cases, the skipper forgot to turn on the video and in others he forgot the correct treatment. Towards the end of the period application of treatments appeared to be ad-hoc with two control hauls initially showing high counts followed by deployment of the mitigation treatment, and lower counts. Similarly, towards the end of the sequence, with low bird abundance and interaction, mitigation was not employed. Despite these treatment hiccoughs the counts of birds moving into the forward area, from astern, were always similar or lower than adjacent control treatments if mitigation was used (Figure 9).

Figure 8. Comparison of counts of small birds taken in real time, counts from Go Pro footage, and counts from EM footage. Breaks in data are different sets.

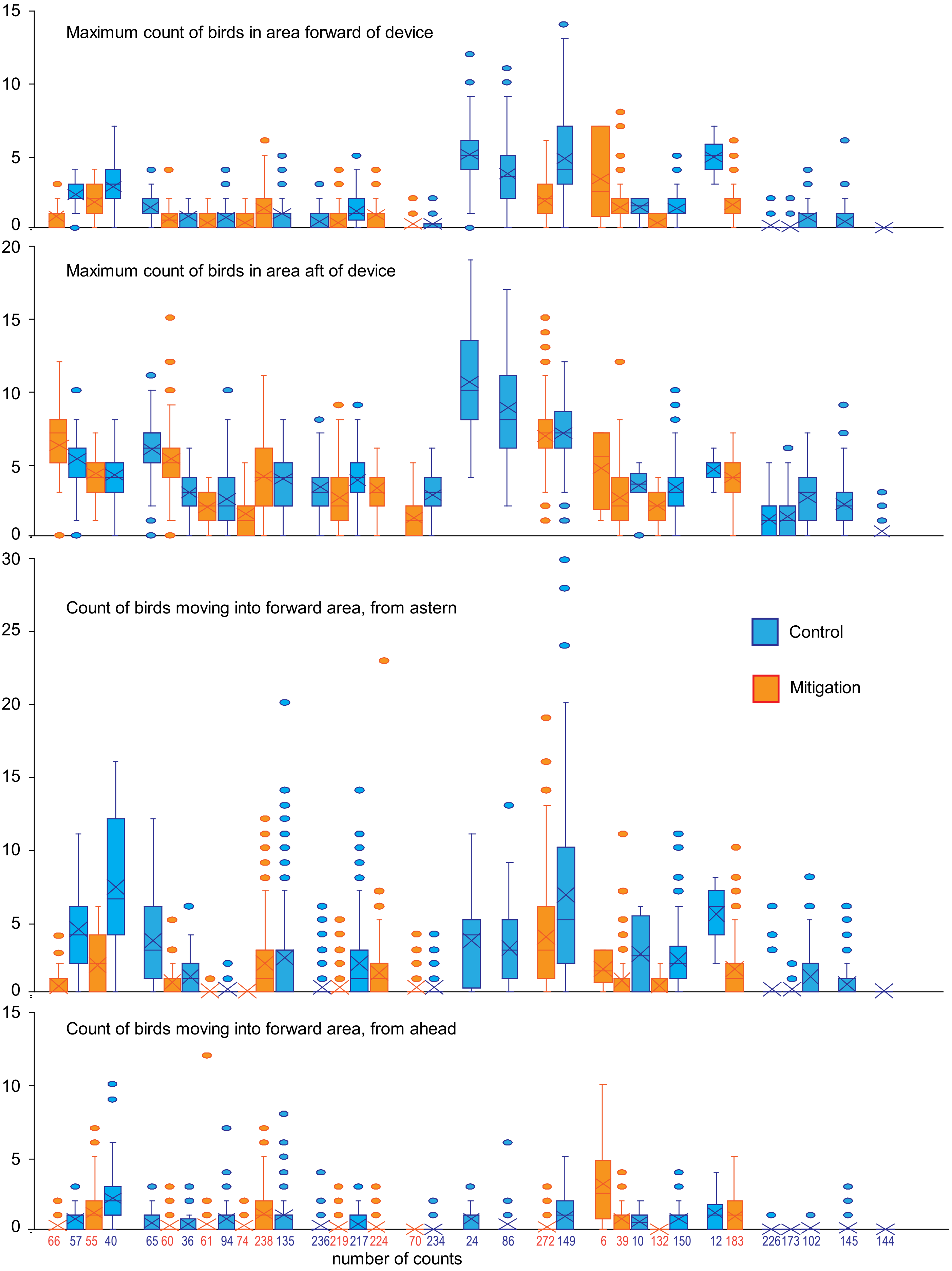


Figure 9. Box-whisker plots by treatment of counts from EM footage on Vessel J (demersal longliner), over the extended period. Breaks in data separate different trips.

During the recovery of intermediate surface floats bird counts and movement into areas were consistently lower than the period immediately prior to recovery (Figure 10).

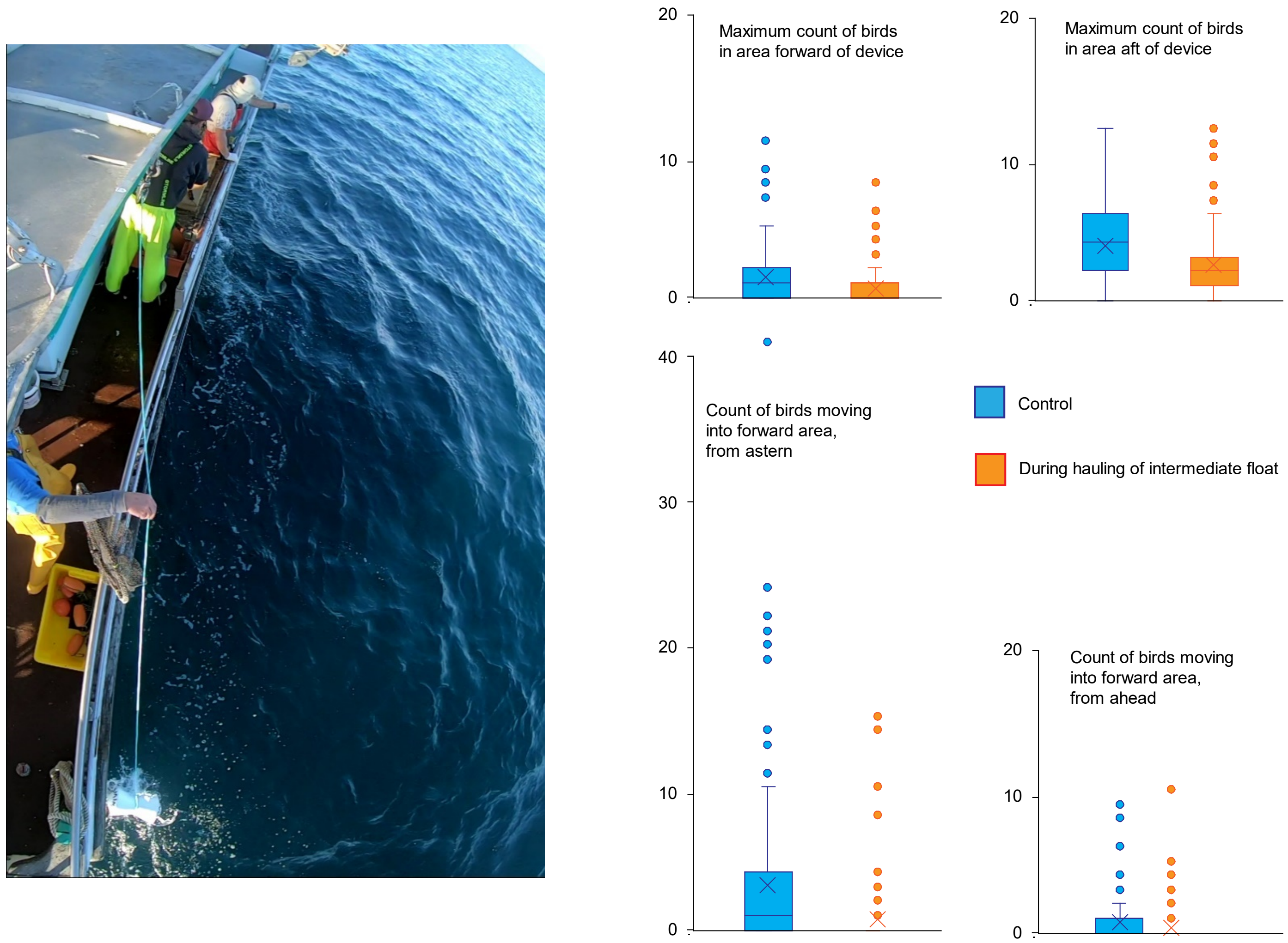


Figure 10. Photograph showing final stages of hauling an intermediate float (bottom left) and bow whisker plots of counts during hauling of intermediate surface floats compared to a control of the last count before the intermediate float was sighted, n = 141 for both treatments.

Pelagic longlining

Neither real time behaviour observations nor Go Pro video observation counts covered the entire haul. Real time observations were alternated with abundance counts, and the time taken to perform abundance counts varied with bird abundance, species composition, and behaviour. Some counts could be almost instantaneous however, with more birds and more activity, counts could take several minutes. To avoid counting individual branchlines, observation periods were from float to float, so typically one basket (or sometimes half a moneymaker basket) was taken up completing each abundance count. Go Pro video counts were more continuous, typically with four interruptions per haul for battery replacement. Go Pro video quality was usually excellent (Figure 11), and adequate for all hauls. Heavy rain, spray, and, on a couple of occasions, fogging of the lens reduced quality but regular checking and cleaning minimised these problems.

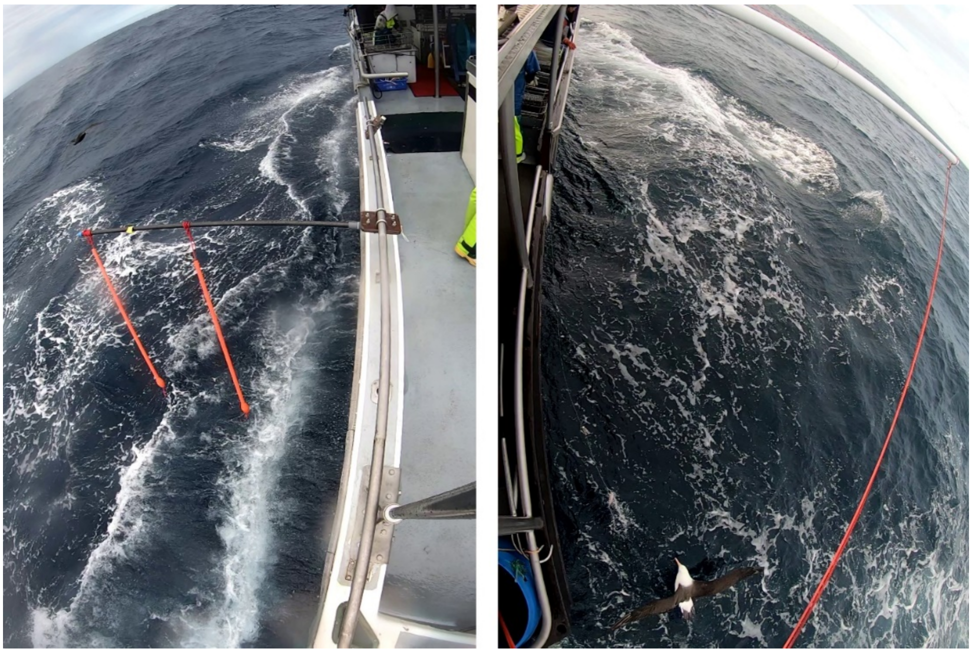


Figure 11. Example snapshots from Go Pro video footage on Vessel T (left), and Vessel C (right).

Interaction and abundance counts were lower in the two winter trips (Figures 12 and 14) compared to the summer trip (Figure 7). Generally video and real time counts compared well, however following baffler and camera repositioning after set two on the second trip on Vessel T (Figure 13) the video field of view appeared to miss some birds in the air.

Broadly speaking, despite low interaction rates in the winter, counts appear to be lower with a mitigation device in place (Figures 12 to 14).

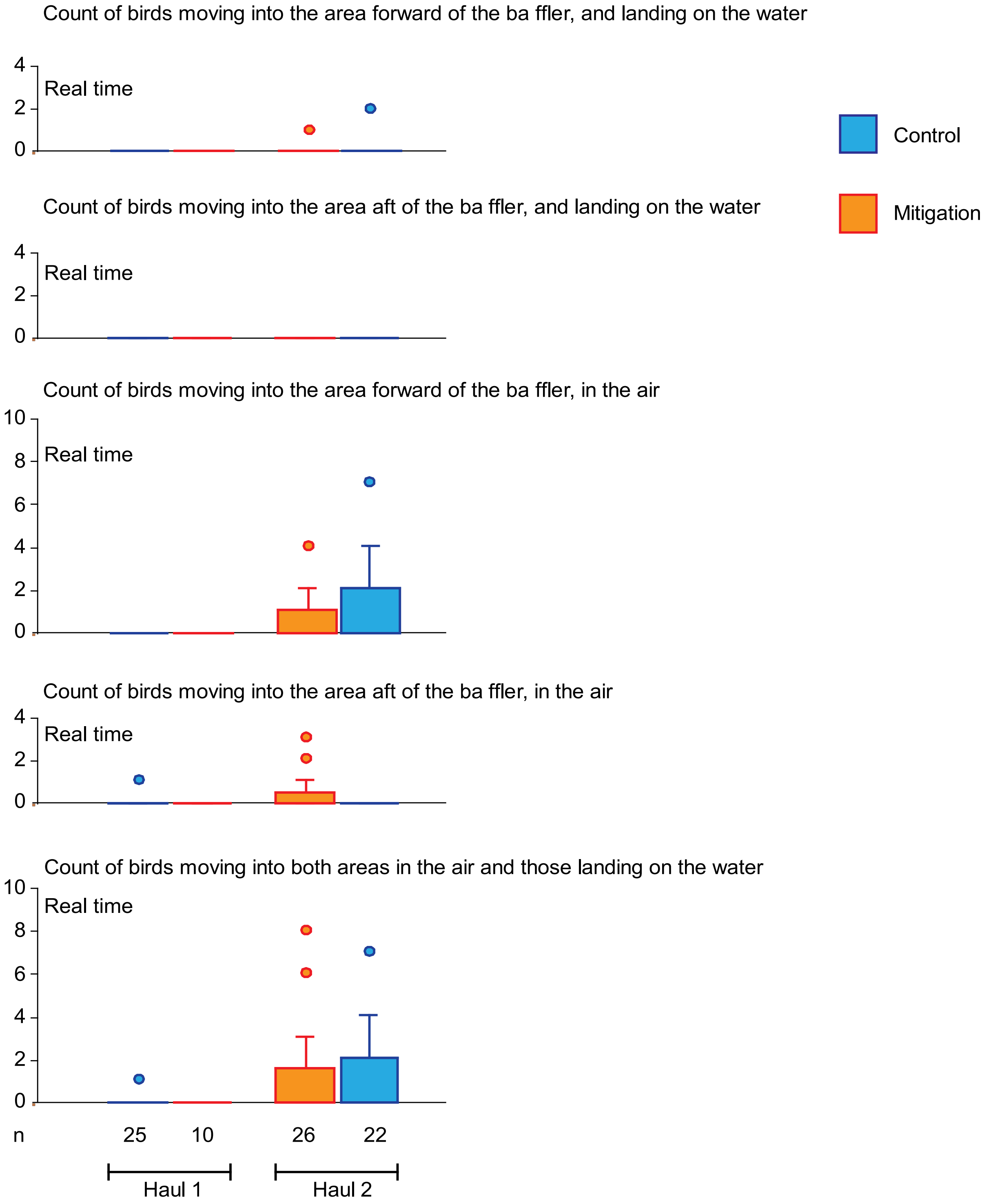


Figure 12. Comparison of counts from trip one on Vessel T, split into different observation areas and whether birds were in the air or on the water, and summed counts including both areas and birds in the air and on the water.

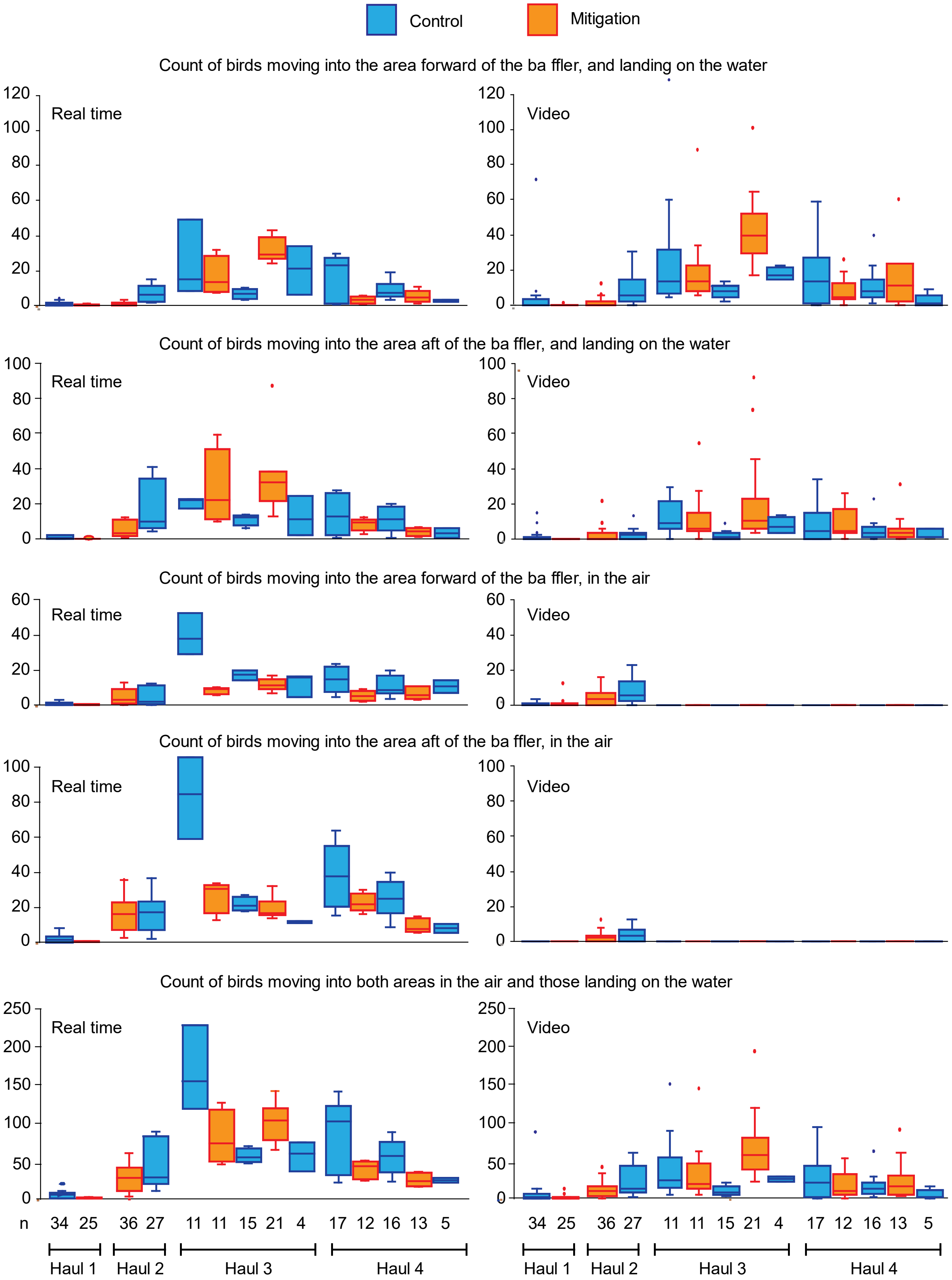


Figure 13. Comparison of real time and video counts from trip two on Vessel T, split into different observation areas and whether birds were in the air or on the water, and summed counts including both areas and birds in the air and on the water.

Counts were lower in the dark (Figure 8).

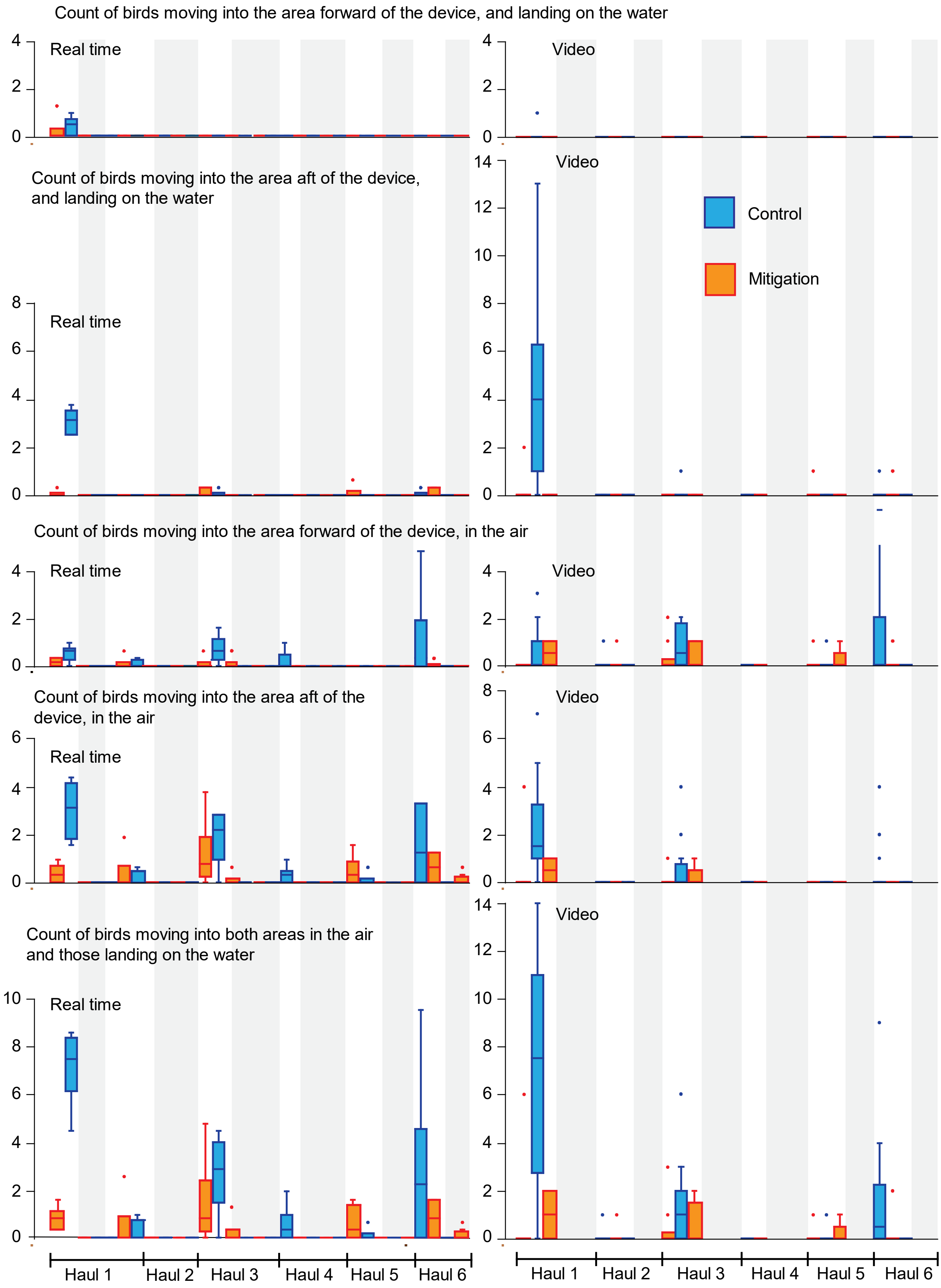


Figure 14. Comparison of real time and video counts from trip Vessel C, split into different observation areas and whether birds were in the air or on the water, and summed counts including both areas and birds in the air and on the water. Shaded areas show darkness, and video footage was not reviewed during these periods.

Composite plots including wind strength and direction relative to the vessel and bird abundance within 100 m help explain count frequencies (Figures 15 to 17). For example, haul three in Figure 16 shows the wind angle was from ahead of the vessel on the hauling side at the start of the haul and then swung around to behind the vessel at the end of the haul. Initially the mitigation produces lower counts, and lower counts still are returned with the wind from abeam, and then counts are higher and the mitigation is ineffective as birds approach the vessel from ahead and dive on baits in front of and beside the hauling station. The final observation period shows lower counts with lower wind speed.

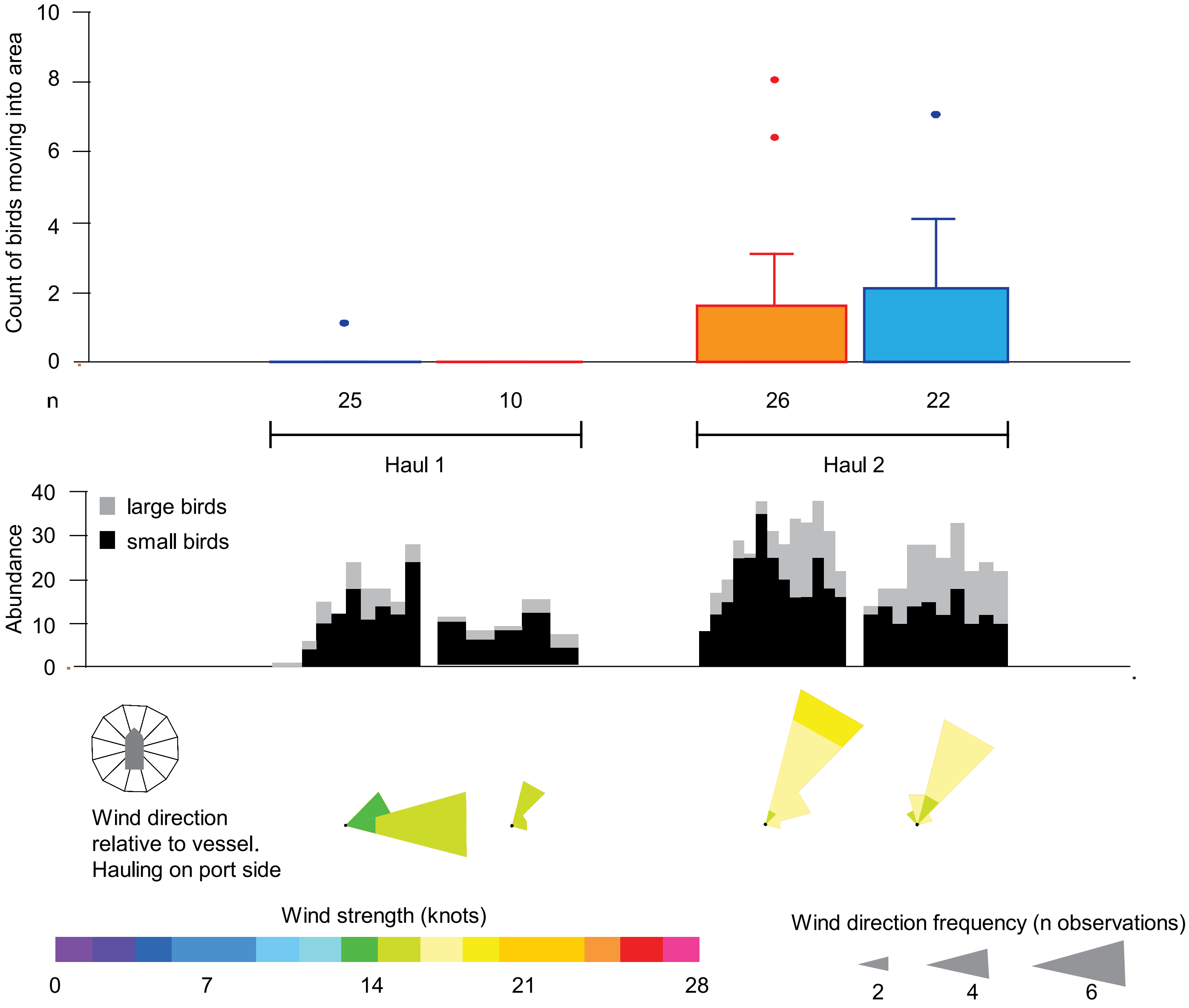


Figure 15. Composite plot of total counts from trip one on Vessel T, including wind direction and strength and bird abundance. Large birds included only albatrosses and giant petrels.

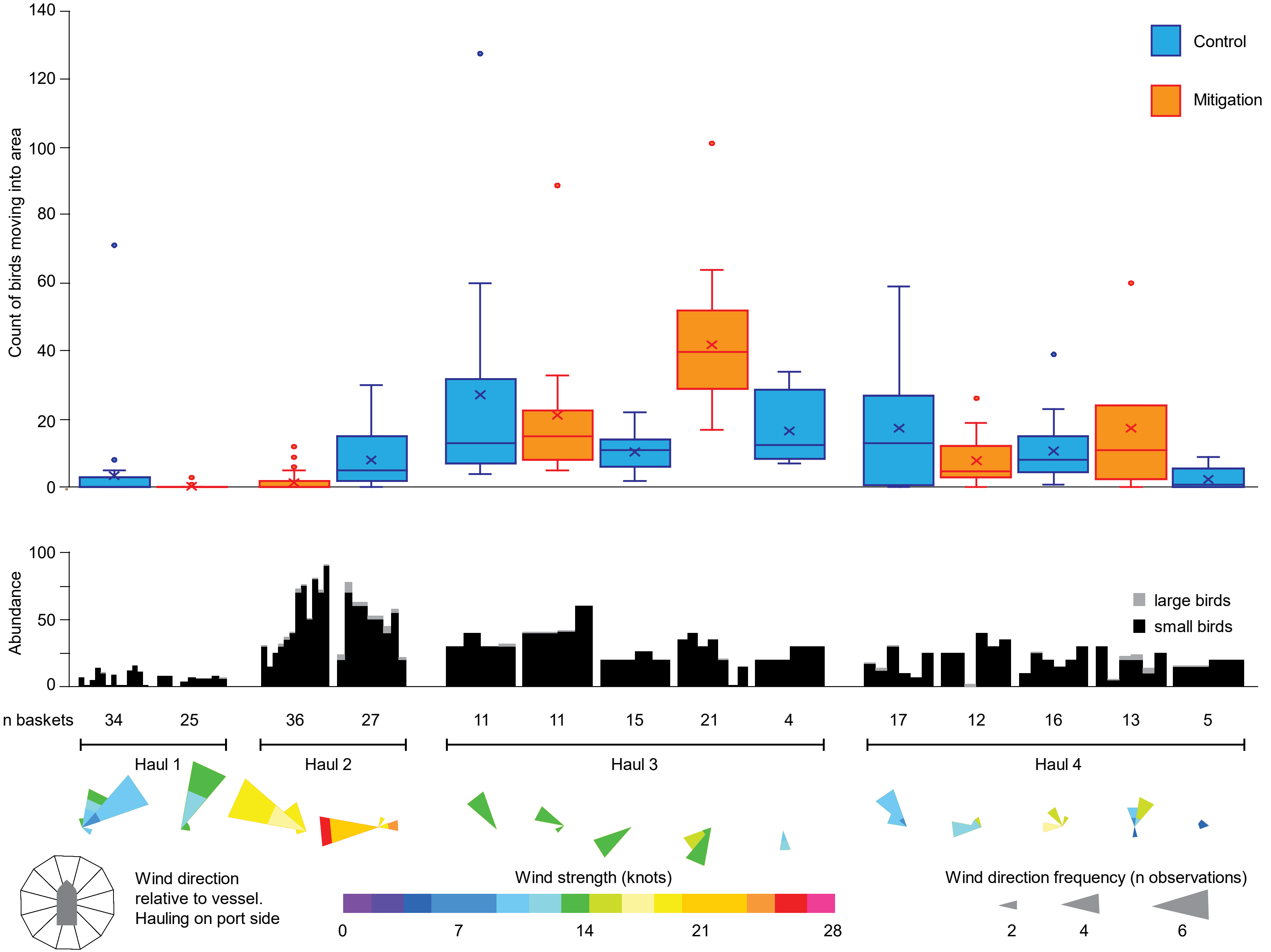


Figure 16. Composite plot of counts of birds moving into the area forward of the mitigation device from trip two on Vessel T, including wind direction and strength and bird abundance. Large birds included only albatrosses and giant petrels.

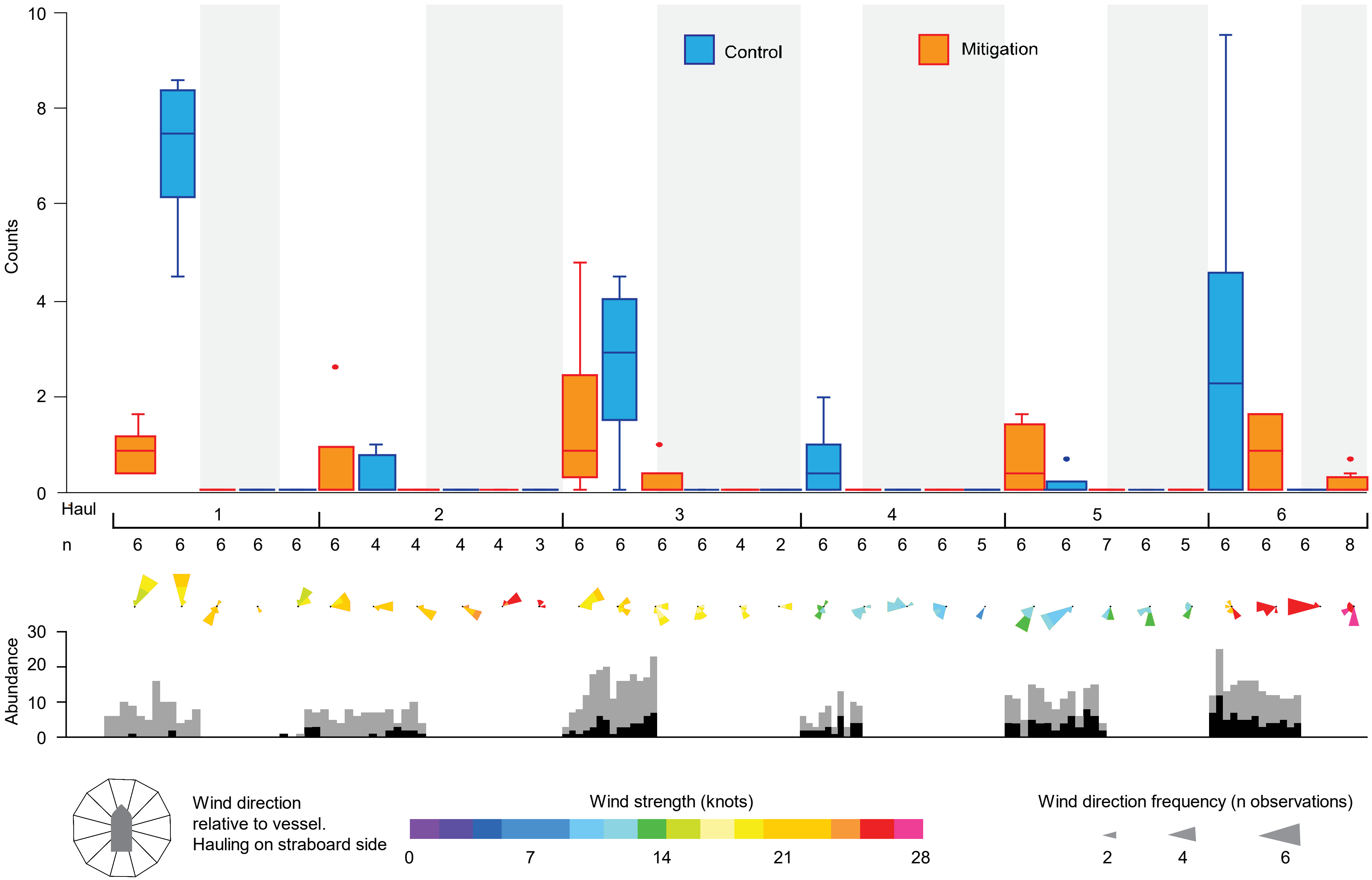


Figure 17. Composite plot of total counts from trip n Vessel C, including wind direction and strength and bird abundance. Large birds included only albatrosses and giant petrels. Shaded areas show darkness.

Counts of dives and contacts did not tie up so well between video and real time counts, however numbers were low (Figure 18).

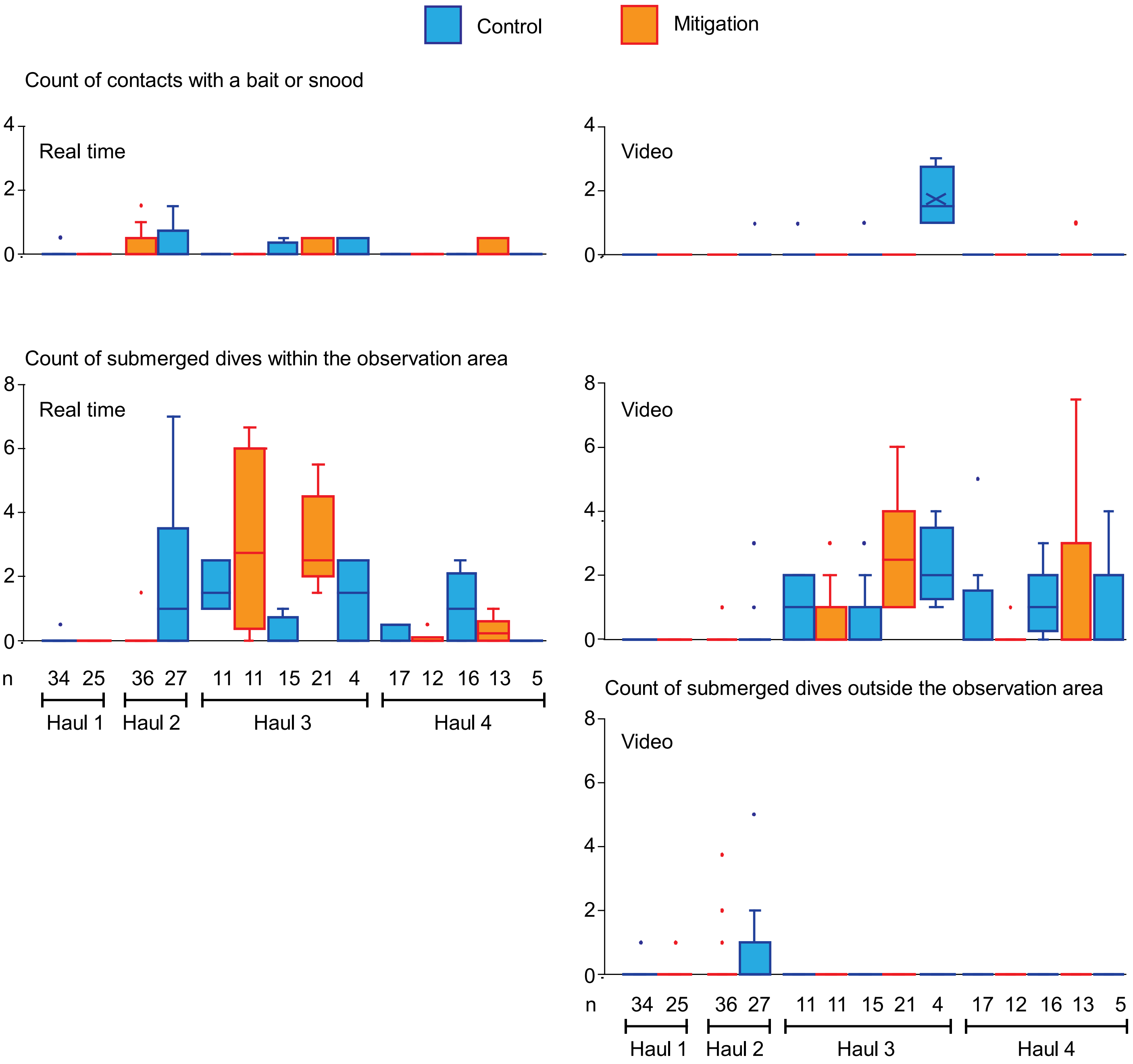


Figure 18. Plots of dives and contacts from trip two on vessel T.

Modelling of real time dataset

The proportion of small birds and proportion of squid bait were selected for the model fitted to observations from pelagic longlines only, and the model fitted to observations from both pelagic and demersal longlines (Table 3). Wind strength was the only additional variable selected for the model fitted to observations from demersal longlines only.

Table 3. Summaries of forward variable selection for models fitted to the real time dataset, with observations from a) pelagic and demersal longlines, b) pelagic longline only, and c) demersal longline only. ΔELPD = increase in expected log pointwise predictive density relative to the previous step.

a) Models fitted to real time data - pelagic and demersal longlines combined

Step	Specification	ΔELPD
Base model	~ offset + treatment + target + (1 | set_id)	-
Step 1	Base model + s(prop small birds, k = 4)	7.0
Step 2	Step 1 + s(prop squid, k = 3)	1.1

b) Models fitted to real time data - pelagic longlines only

Step	Specification	ΔELPD
Base model	~ offset + treatment + target + (1 | set_id)	-
Step 1	Base model + s(prop small birds, k = 4)	6.4
Step 2	Step 1 + s(prop squid, k = 3)	1.5

a) Models fitted to real time data - demersal longlines only

Step	Specification	ΔELPD
Base model	~ offset + treatment + (1 | set_id)	-
Step 1	Base model + s(wind strength, k =4)	3.5

The usage of a mitigation device resulted in a reduced rate of seabirds entering the area forward of the mitigation device for models fitted to observations from both pelagic and demersal longlines (Appendix 1, Figure 19; mitigation effect = -0.79, 95% c.i. -1.02 to -0.55), pelagic longlines only (Figure 20; mitigation effect = -0.74, 95% c.i. -1.03 to -0.46) and demersal longlines only (Appendix 1, Figure 21; mitigation effect = -1.01, 95% c.i. -1.42 to -0.58).

Increasing proportions of small birds within 100 m of the vessel, and increasing proportions of squid bait, were both associated with decreasing rates of seabirds entering the area forward of the mitigation device for the models fitted to observations from both pelagic and demersal longlines (Appendix 1, Figure 19), and to observations from only pelagic longlines (Appendix 1, Figure 20).

Pelagic longlines targeting southern bluefin tuna ('STN') were associated with lower rates of seabirds entering the area forward of the mitigation device, for both the model fitted to observations from pelagic and demersal longlines (Appendix 1, Figure 19) and pelagic longlines only (Appendix 1, Figure 20).

For the model fitted to observations from demersal longlines only, increasing wind strength from 0 to 10 knots was associated with increasing rates of seabirds entering the area forward of the mitigation device, with rates remaining constant as wind strength increased from 10 knots (Appendix 1, Figure 21).

Modelling of the EM dataset

The presence of a mitigation device resulted in a reduced rate of seabirds entering the area forward of the mitigation device for the model fitted to the full electronic monitoring dataset (Appendix 1, Figure 22; mitigation effect = -1.17, 95% c.i. -1.36 to -0.97).

For the model fitted to the float-focussed subset of the electronic monitoring dataset, the presence of a mitigation device (mitigation effect = -1.35, 95% c.i. -2.34 to -0.36) and hauling of an intermediate float (float effect = -1.97, 95% c.i. -2.55 to -1.42) were both associated with lower maximum counts of seabirds in the area forward of the mitigation device (Appendix 1, Figure 23). The combined effect of hauling an intermediate float and the usage of a mitigation device was weaker than the sum of the individual effects due to the interaction term (Appendix 1, Figure 23 and 24).

Discussion

It was not deemed practical to fully enclose the hauling station on small vessel demersal or pelagic longliners, so the designs presented here aimed to measurably reduce risk with minimal impact on fishing operations. This is particularly important when introducing 'extra' mitigation, and when uptake is voluntary. A dangler-type approach was favoured by skippers for ease of use and a similar approach seemed appropriate for both fisheries. The long branchlines, high bait returns, and large areas of availability, especially to diving birds, make reducing interactions most challenging in the pelagic longline fishery.

Despite reasonable numbers of birds attending vessels, direct interactions with the fishing gear were rare, and only two captures were observed. This poses challenges when trialling mitigation, especially when interaction rates are partially driven by uncontrollable variables such as time, place, and weather conditions. The use of proxy measures, either counts in areas deemed high risk, or counts of movement into these areas, worked well and, when combined with modelling, allowed for comparison between treatments. Quantifying risk by hooks for pelagic longline and hauling time for demersal longline was most appropriate.

All models detected reductions in the rates of seabirds entering the area forward of the mitigation device when mitigation was used. This showed that simple devices, more suitable for small vessels than those employed by large autoliners (e.g. Reid et al., 2010), reduced risk to birds.

The collection of data in real time allowed for recording of additional variables, albeit over shorter time periods. As these variables tended to be similar within sets there was limited statistical power to explore and identify relationships between environmental variables and the rate of seabirds entering the area forward of the mitigation device. Relatedly, it was apparent during the variable selection process that there was generally relatively weak support for adding additional variables to the models fitted to real time data, and generally relatively similar levels of support for the different candidate covariates considered. For example, models including effects for swell and wind direction detected plausible relationships with the rates of seabirds entering the area forward of the mitigation device.

The real time dataset had more observations from pelagic longlines, and as such the model fitted to both pelagic and demersal longline data is largely driven by the pelagic longline data. Additional real time data from demersal longlines would be helpful in assessing differences between pelagic and demersal longlines.

Squid bait is commonly noted by fishers to be less attractive for birds and the model results support this. Whilst demersal longline skippers tend to prefer a mixture of fish and squid pelagic longline skippers are often happy using straight squid, which appears to reduce risk. On vessel T the skipper's main reason for including sanma was its relatively low cost.

Increasing proportions of small birds were associated with decreasing rates of seabirds entering the area forward of the mitigation device, and this is likely driven by the pelagic longline trip where flesh-footed shearwaters were targeting sanma baits well forward of the vessel, outside of the observation area.

Whilst wind direction was observed to influence bird behaviour around the boat (e.g. Figure 16) additional observations would be required to further explore the effects statistically. When pelagic longlining, skippers tend to set gear relative to the wind, often setting downwind and hauling into the wind. Whilst hauling into the wind potentially allows birds better access to the hauling area, shooting downwind similarly reduces access to hooks at the set. Arguably, having a 'bird friendly' wind direction is still more advantageous during the set, despite recent improvements to setting mitigation. Demersal longliners, however, are generally more flexible with shooting direction and, with shorter lines, more commonly haul and shoot in the same direction. Therefore, especially at high-risk times, setting and hauling downwind may be another tool in the mitigation toolbox. Unsurprisingly, low wind strengths reduced counts of birds moving into the area beside the hauling station. This can be explained by birds having to expend a lot more energy to manoeuvre below 10 to 12 knots windspeed, above which they can often glide, relatively effortlessly.

Hauling of intermediate floats on demersal longliners consistently reduced bird abundance at the hauling station, and the model showed a significant difference, unsurprisingly with an interaction with mitigation. This shows that a towed object / tori line approach is also effective during hauling. Whilst it may not be practical in all instances, leaving intermediate floats trailing astern from the hauling station is an easy option to implement and may provide additional protection without the need for extra equipment. For vessels hauling over the stern this approach is particularly effective and hassle-free (B. Kiddie pers comm).

Hauling in the dark on vessel C consistently returned zero or very low bird counts indicating that, in itself, this is reducing attendance at the hauling station. This is typical practice during the short winter days of the bluefin fishery, particularly if catches are good and lines take longer to haul. How applicable this is as a mitigation measure will vary by fishery, but it should be encouraged where practical.

The review of two types of video footage produced similar results to real time observations. In this case it did not result in major time or cost savings as processing time was considerable. Importantly, EM footage was adequate and with planned improvements to hardware and camera placement more accurate data could be collected more quickly. Moving the camera outboard would provide a better view of the area of interest, and a second camera could be used to collect abundance data at greater distances from the vessel. Sealed nitrogen filled housings would eliminate lens fogging and lens coatings to shed rainwater and sea spray would improve clarity in poor weather. Similarly, regular cleaning of the lens is always going to be necessary and some automated assessment of image quality to trigger a prompt for crew to clean the lens would improve image quality.

Given the time taken to review footage it is worth considering tagging routine review of EM footage with the mitigation measures in place, at both the set and haul, such that a more in-depth analysis of captures could be performed with little extra effort. Automated logging of wind strength and direction, swell height, and light levels should also be possible with off-the-shelf sensors.

Generally speaking, for controlled experiments either with or without observers or technicians on board, video footage is a useful and emerging tool for measuring seabird behavioural response to mitigation measures, including estimates of abundance (e.g. Gilman et al., 2021).

One limitation when conducting trials with video footage, and without a technician on board, is precise execution of treatments. This was lacking for the full EM series here, due to ad-hoc implementation of mitigation by the skipper towards the end of the time period. Swapping treatments on a haul-by-haul basis was deemed easiest for the skipper however, given the variation in environmental conditions, within-haul changes in treatments is preferable and likely to increase statistical power.

Conclusions

Results and feedback from skippers show that the simple, cheap, and hassle-free designs presented here are acceptable to fishers and reduce, but not eliminate, risk to birds during hauling.

Encouraging uptake across the fleet will reduce risk to birds and, once skippers become used to including hauling mitigation as a part of their operation, they may well be prepared to develop more elaborate and effective designs. On some demersal longliners it may be possible to use a towed intermediate surface float as hauling mitigation.

The nature of pelagic longline gear provides a much larger area in which birds can access hooks and whilst the designs presented here afford a measure of protection for hooks at the surface, diving birds were able to access hooks well forward of the vessel, which is hard to mitigate.

The use of video footage, including EM derived footage, was adequate for assessing the efficacy of mitigation, however in this case the cost savings weren’t huge. With this in mind quantifying mitigation use and capturing this data when routinely reviewing EM data should be encouraged.

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Appendix 1. Model description and results

Data analysis methods

All data analysis was undertaken in R 4.0.3 (R Core Team, 2020), with models fitted using Bayesian Markov chain Monte Carlo (MCMC) methods using the Stan programming language via the RStan package (Stan Development Team, 2020). Separate models were fitted to three datasets: real time data collected from all three vessels; the full electronic monitoring dataset from vessel J; and, a subset of the electronic monitoring data from vessel J focussing on the effect of hauling intermediate floats on seabird counts. Models were fitted using four chains each of 2,000 iterations, including a burn-in period of 1,000 iterations. Diagnostics used to assess model fit were primarily based on posterior predictive checks, and convergence was assessed using $\hat{R}$ diagnostics.

Models fitted to the real time dataset
Stan-programmed models were constructed using the brms package (Bürkner. 2018). A negative-binomial likelihood was used to account for overdispersion, with a log-link function. Thin-plate regression splines were used where appropriate to account for non-linear effects of covariates. Models were fitted to data from both pelagic and demersal longlines, with pelagic and demersal longline specific models also fitted to explore for variation between the two fisheries.

The response variable was the count of the seabirds moving into the area forward of the mitigation device, noting that an individual bird may have been counted several times if it moved in and out of the area during the observation period. All models included an offset term to account for both the number of birds within 100 m of the vessel during the observation, and the duration of the observation.

The duration of an observation was defined as the number of hooks hauled for pelagic longlines, and the length of the observation period in minutes for demersal longlines. For models fitted to observations from both pelagic and demersal longlines, duration was standardised for each fishery by dividing by the fishery-specific mean duration. As such, the models should be interpreted as modelling the rate of seabirds entering the area forward of the mitigation, defined as numbers per hook per bird within 100 m for pelagic longlines, and numbers per minute per bird within 100 m for demersal longlines.

Observations with no seabirds within 100 m of the vessel were excluded from the modelled dataset, as these do not provide information on the effects of mitigation and other covariates on the rate of seabirds moving into the area forward of the mitigation device. This removed all fishing events where gear was hauled at night time.

A forward-selection procedure was used to select covariates using leave-one-out cross validation based on expected log pointwise predictive density (ELPD – see Vehtari et al, 2017). Covariate selection started from a base model including a 'treatment' effect (i.e. mitigation vs no mitigation) and a random intercept for set id to account for the structure of the dataset, i.e. repeated observations from specific sets. A target species effect was also included in the base model when fitting to observations from pelagic longlines given the observed between-target variation in seabird species assemblages attending the pelagic longliners. The target effect was not required for models fitted exclusively to demersal longlines, as all observed sets were targeting snapper. Candidate covariates explored in the forward-selection procedure included: wind direction relative to the hauling station (12 = within 15° either side of dead ahead, 1 = 15 to 45° from ahead on hauling side, 2 = 45 to 75° from ahead on hauling side, …); swell height (m); swell direction relative to the hauling station (using the same scale as for wind direction); and, the proportion of squid bait. Additionally, when pelagic longline observations were included in the modelled dataset, the candidate covariates also included the proportion of seabirds within 100 m of the vessel that were defined as 'small', i.e. not albatross or giant petrel species. This covariate was not required for models that were fitted exclusively to observations from demersal longlines, as all seabirds within 100 m of the demersal longlines were defined as small.

The variance of a negative binomial distribution is commonly modelled as

$$\mu + \frac{\mu^2}{\theta}$$

where μ is the mean, and θ controls for overdispersion.

In exploratory models, it was apparent that model fits were improved when implementing an alternative parameterisation of the negative binomial likelihood which allows more flexibility in the modelling of overdispersion. Following Tremblay-Boyer & Abraham (2020), we modelled the variance as

$$\mu + \frac{\mu^2}{\mu^{\upsilon}\theta}$$

which requires an additional parameter $\upsilon \in (0, 2)$.

The base model structure for models fitted to data exclusively from demersal longlines was

$$\mathbb{E}[y_{ij}] = \mu_{ij}$$

$$\mathrm{Var}(y_{ij}) = \mu_{ij} + \frac{\mu_{ij}^2}{\mu_{ij}^{\upsilon}\theta}$$

$$\mu_{ij} = \log(n_{ij}) + \log(duration_{ij}) + \beta_0 + treatment_{ij} + b_j$$

where subscripts i and j refer to observation and fishing event ID respectively, y_{ij} is the count of seabirds moving into the area forward of the mitigation device, n_{ij} is the number of seabirds within 100 m of the vessel, $duration_{ij}$ was the duration of the observation (defined above), θ and υ control overdispersion, $treatment_{ij}$ is a categorical variable for 'treatment', i.e. mitigation vs no mitigation, and b_j is a random intercept for set. The base model structure when fitting to pelagic longline observations, or observations from both pelagic and demersal longlines, had an additional categorical variable for target species.

The modelled real time dataset for pelagic longlines consisted of 206 observations from 12 fishing events. Six fishing events were from one trip on vessel C, targeting southern bluefin tuna (STN). The remaining 6 fishing events were from two trips on vessel T, with one trip (four events) targeting bigeye tuna (BIG) and one trip (two events) targeting southern bluefin tuna. The mean number of hooks per observation period was 29.0 (s.d. = 4.6), with a mean of 21.5 birds within 100 m of the vessel (s.d = 19.4). The mean count of seabirds entering the area forward of the mitigation device was 13.3 (s.d.= 27.2). The modelled data for demersal longlines consisted of 76 observations from 9 fishing events, all from vessel J and all targeting snapper (SNA). The mean duration of each observation period was 14.6 minutes (s.d. = 3.9), with a mean of 13.6 birds within 100m of the vessel (s.d. = 11.7). The mean count of seabirds entering the area forward of the mitigation device was 15.8 (s.d. = 19.8).

Models fitted to the full EM dataset

Models were fitted to the full electronic monitoring dataset from vessel J and used to test the efficacy of the mitigation device. A negative-binomial likelihood was assumed with a log link function. The response variable was the count of seabirds moving into the area forward of the mitigation device, with each record in the dataset representing an observation period of one minute. As such, the model response should be interpreted as the rate of seabirds moving into the area forward of the mitigation device per minute. The specification of the model was

$$\mathbb{E}[y_{ij}] = \mu_{ij}$$

$$\mathrm{Var}(y_{ij}) = \mu_{ij} + \frac{\mu_{ij}^2}{\theta}$$

$$\log(\mu_{ij}) = \beta_0 + treatment_{ij} + b_j$$

where subscripts i and j refer to observation and day ID respectively, y_{ij} is the count of seabirds moving into the area forward of the mitigation device, θ controls overdispersion, $treatment_{ij}$ is a categorical variable for 'treatment', i.e. mitigation vs no mitigation, and b_j is a random intercept for day to account for repeated observations from the same fishing event, and therefore day.

The modelled full EM dataset consisted of 4,043 observations from 169 days, all from vessel J. The mean count of seabirds entering the area forward of the mitigation device was 2.0 (s.d. = 3.3).

Models fitted to the float-focussed EM data subset

Models were fitted to a subset of the EM dataset to specifically explore the effect of mitigation in combination with the hauling of intermediate floats. Each record represented an observation period of one minute, and the response variable was the maximum count of seabirds in the area forward of the mitigation device during the minute. Records were paired such that each 'treatment' record comprised a minute during which a float was hauled and the corresponding 'control' treatment was a minute immediately before the float was visible. Otherwise, the model structure was equivalent to that fitted to the full EM dataset, but with the inclusion of a categorical variable effect for area, i.e. float vs control, as well as an interaction term between the treatment and area effects, i.e.

$$\mathbb{E}[y_{ij}] = \mu_{ij}$$

$$\mathrm{Var}(y_{ij}) = \mu_{ij} + \frac{\mu_{ij}^2}{\theta}$$

$$\log(\mu_{ij}) = \beta_0 + treatment_{ij} * area_{ij} + b_j$$

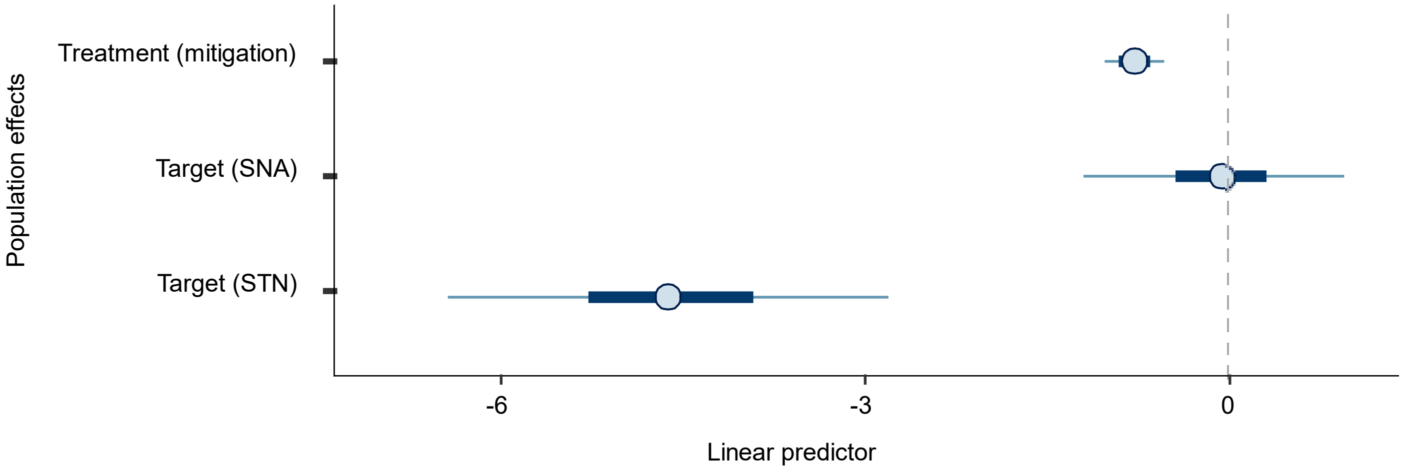
where subscripts i and j refer to observation and day ID respectively, y_{ij} is the maximum count of seabirds in the area forward of the mitigation device, θ controls overdispersion, $treatment_{ij}$ is a categorical variable for 'treatment' (i.e. mitigation vs no mitigation), $area_{ij}$ is a categorical variable ('float' = during hauling of an intermediate, 'control' = the period immediately before hauling the intermediate float), and b_j is a random intercept for day.

The modelled float-focussed EM dataset consisted of 282 observations from 30 days. The mean maximum count of seabirds in the area forward of the mitigation device was 2.4 (s.d. = 5.3).

Model Results

Modelling of real time dataset

a) Categorical variables for the model fitted to real time data - pelagic and demersal longlines combined, relative to the control mitigation treatment and BIG target



b) Splines for the model fitted to real time data - pelagic and demersal longlines combined

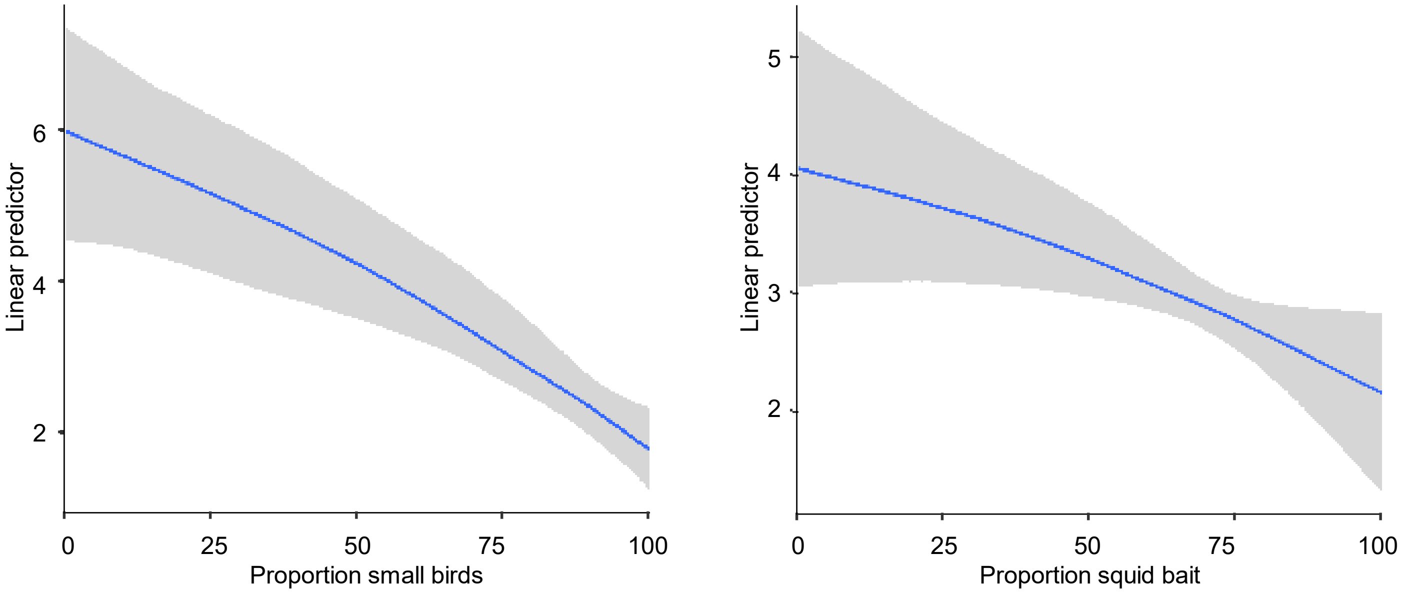
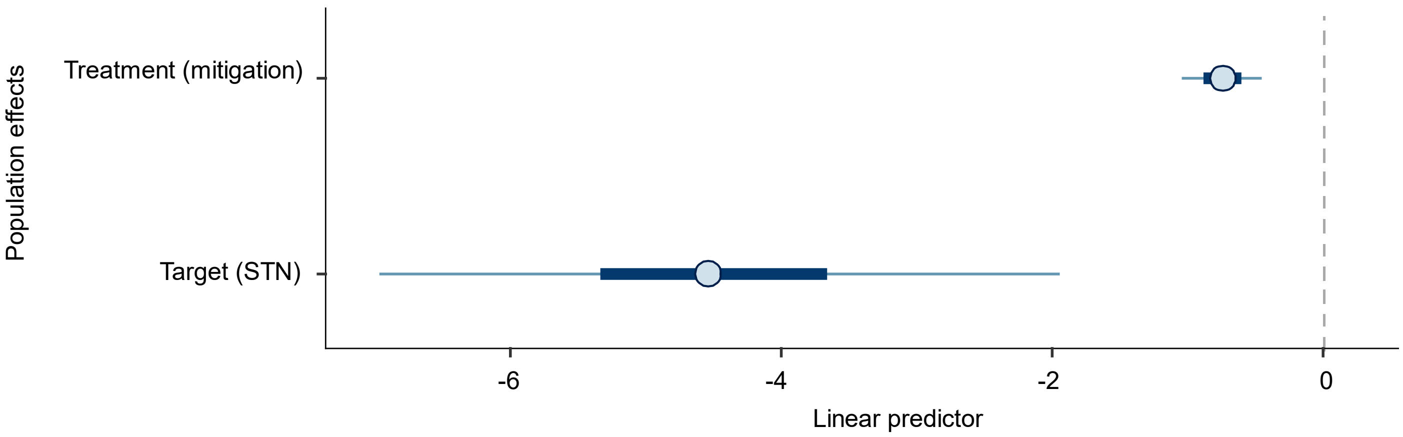


Figure 19. a) Parameters for categorical variables, and b) splines for the selected model fitted to real-time data from combined pelagic and demersal longlines. The linear predictor is on the log-scale. 'Control' and 'BIG' were the reference levels for the treatment and target terms respectively, and so have an effect size of 0. The thick bars and thin lines of the parameter estimates give the 50% and 95% credible interval respectively. The shaded region of the splines gives the 95% credible interval.

a) Categorical variables for the model fitted to real time data – pelagic longlines only



b) Splines for the model fitted to real time data – pelagic longlines only

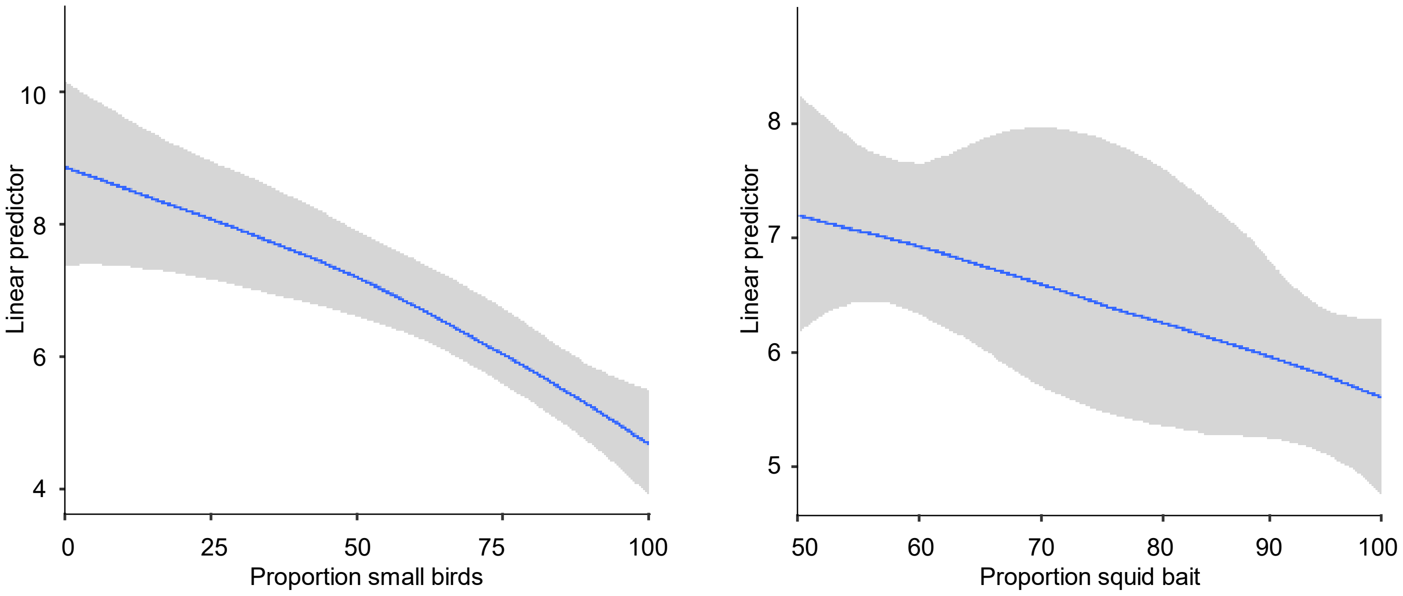
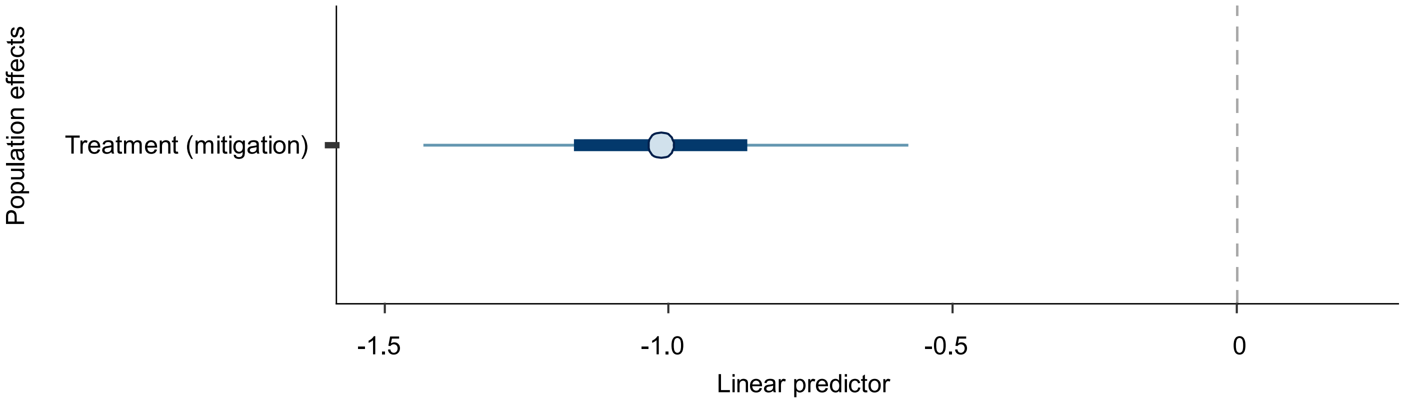


Figure 20. a) Parameters for categorical variables and b) splines for the selected model fitted to real-time data from pelagic longlines. The linear predictor is on the log-scale. ‘Control’ and ‘BIG’ were the reference levels for the treatment and target terms respectively, and so have an effect size of 0. The thick bars and thin lines of the parameter estimates give the 50% and 95% credible interval respectively. The shaded region of the splines gives the 95% credible interval**.**

a) Categorical variables for the model fitted to real time data – demersal longlines only



b) Splines for the model fitted to real time data – demersal longlines only

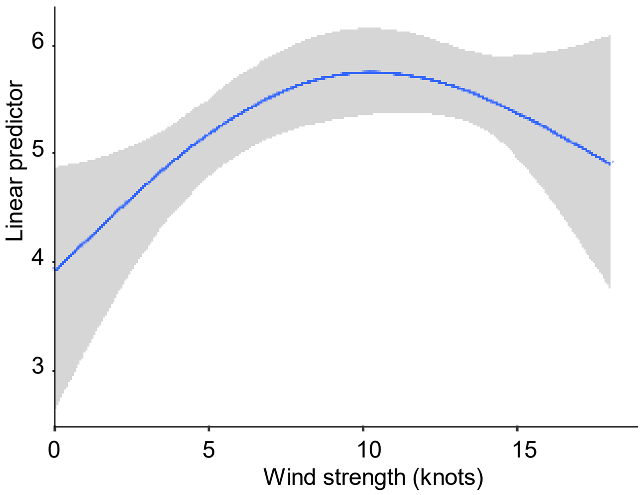


Figure 21. a) Parameters for categorical variables and b) splines for the selected model fitted to real-time data from demersal longlines. The linear predictor is on the log-scale. ‘Control’ was the reference level for the treatment term, and so has an effect size of 0. The thick bars and thin lines of the parameter estimates give the 50% and 95% credible interval respectively. The shaded region of the splines gives the 95% credible interval.

Modelling of the EM dataset

The presence of a mitigation device resulted in a reduced rate of seabirds entering the area forward of the mitigation device for the model fitted to the full electronic monitoring dataset (Figure 22; mitigation effect = -1.17, 95% c.i. -1.36 to -0.97).

For the model fitted to the float-focussed subset of the electronic monitoring dataset, the presence of a mitigation device (mitigation effect = -1.35, 95% c.i. -2.34 to -0.36) and hauling of an intermediate float (float effect = -1.97, 95% c.i. -2.55 to -1.42) were both associated with lower maximum counts of seabirds in the area forward of the mitigation device (Figure 23). The combined effect of hauling an intermediate float and the usage of a mitigation device was weaker than the sum of the individual effects due to the interaction term (Figure 23 and 24).

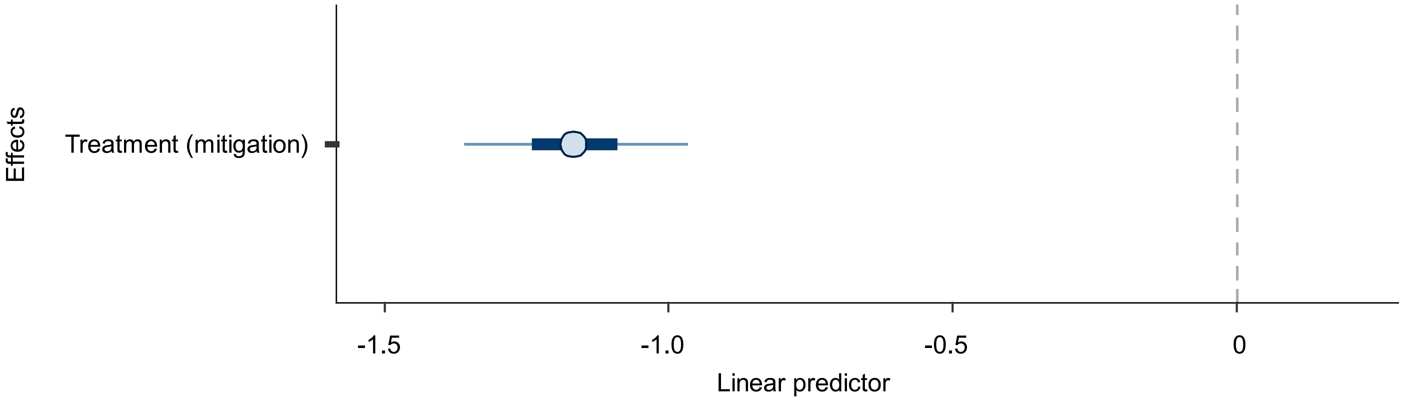


Figure 22. The estimated mitigation effect for the model fitted to the full EM dataset. The linear predictor is on the log-scale. ‘Control’ was the reference level for the treatment term, and so has an effect size of 0. The thick bars and thin lines of the parameter estimates give the 50% and 95% credible interval respectively.

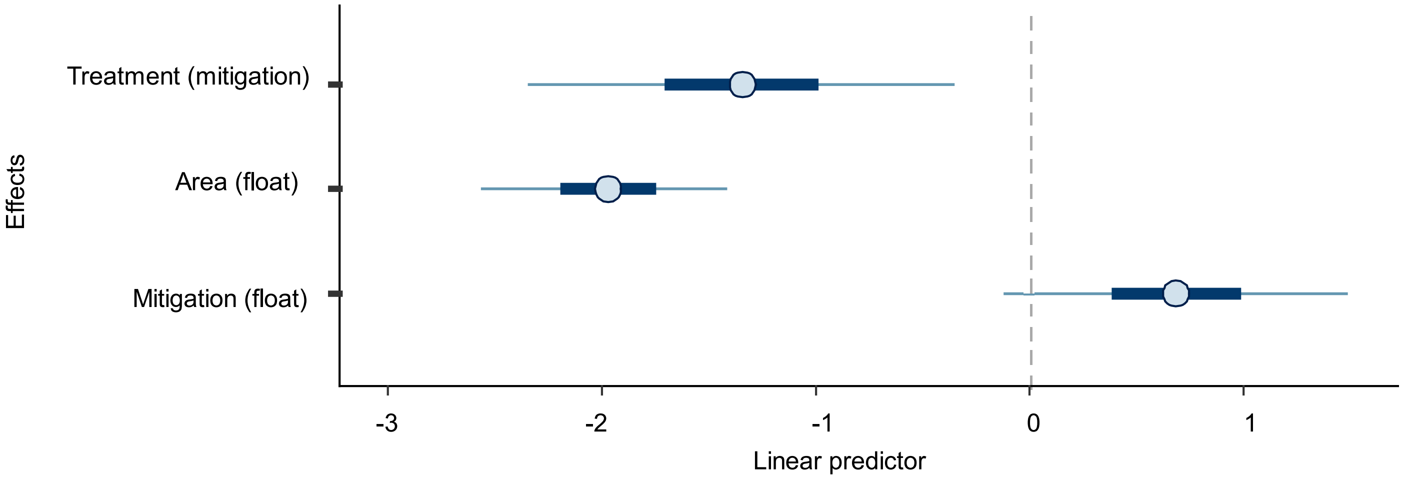


Figure 23. The estimated mitigation effect, float effect, and mitigation-float interaction for the model fitted to the float-focussed EM data subset. The linear predictor is on the log-scale. ‘Control’ and ‘not hauling a float’ were the reference levels for the treatment and area terms, and so have an effect size of 0. The thick bars and thin lines of the parameter estimates give the 50% and 95% credible interval respectively.

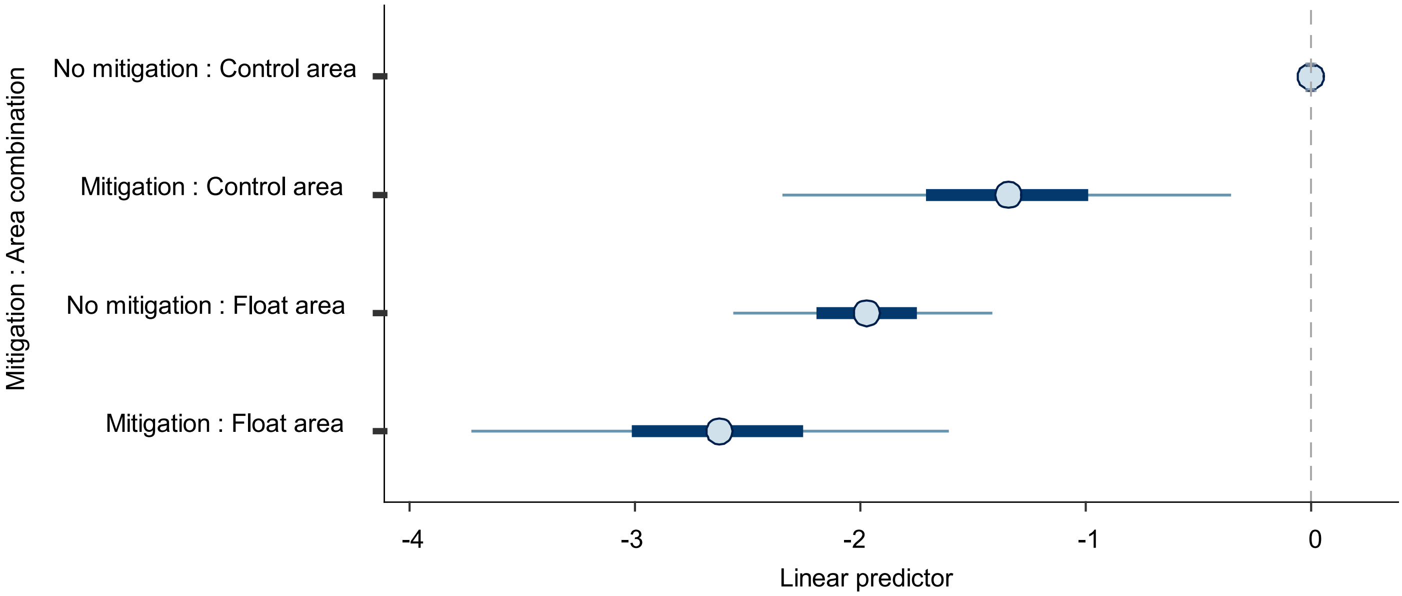


Figure 24. The combined effect of the treatment and area terms on the linear predictor, from the model fitted to the float-focussed EM data subset. The linear predictor is on the log-scale. The thick bars and thin lines of the parameter estimates give the 50% and 95% credible interval respectively.