Whale entanglements with New Zealand pot fisheries: characterisation and opportunities for management

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Executive summary

Cetacean entanglements have occurred globally in pot and trap fishing gear for decades. Entanglements typically occur in the vertical ropes connecting the pot/trap to a position marker (such as a buoy or float) at the sea surface. Entanglements can result in injuries and mortalities, with negative consequences for both animal welfare and potentially cetacean population persistence. Methods to reduce cetacean interactions with pot and trap fishing gear, and the impacts of entanglements, include gear modifications, spatial/temporal management, and disentanglement interventions. In New Zealand waters, cetacean entanglements with pot fishing gear have been documented since 1980. From 1980 to the present, 1-2 entanglement events per year have been reported on average. However more recently, from 2010 – 2020, an average of 4-5 entanglement events per year have been recorded. Disentanglement interventions are the main documented approach to addressing this issue in New Zealand to date.

In this project, we update previous work on cetacean entanglements in New Zealand waters. We consider spatial and temporal trends in pot fishing effort, and entanglement information held by the Department of Conservation. We also review recent entanglement mitigation information and consider mitigation and management methods investigated in other jurisdictions. Further, we convened a workshop of expert stakeholders to share information, better understand entanglement risks and issues in the New Zealand rock lobster fishery, and proactively consider how to manage the entanglement issue with industry involvement.

In New Zealand waters, pot fishing occurs in all Fisheries Management Areas except FMA 10 (Kermadec). Fishing effort reported has declined significantly from 1990 to 2021, with this decline driven by a reduction in pot fishing effort targeting rock lobster (*Jasus edwardsii*). Pot fishing targeting other species represents <10% of effort on average. Other species targeted with this method include packhorse lobster (*Jasus verreauxi*), ling (*Genypterus blacodes*), blue cod (*Parapercis colias*), paddle crab (*Ovalipes catharus*), and hagfish (*Eptatretus cirrhatus*). Pot fishing occurs around the main islands of New Zealand, and the Chatham Islands, with effort varying monthly among target species. Pot soak times vary within and between target species.

Since 1980, entanglements in pot fishing gear have been detected along the north-east coast of the North Island, Cook Strait and Marlborough, east coast of the South Island, and Fiordland and Stewart Island. Most recorded entanglements over time have involved humpback whales (*Megaptera novaeangliae*; 62%), followed by orca (*Orcinus orca*; 16%). Most entanglements have been reported in June, with almost all of these involving humpback whales. Orca entanglements have occurred in the spring and summer months. Entanglement events involving other cetacean species comprise 22% of those reported, and have occurred occasionally through the year. Ecological factors relevant to entanglements are generally not well understood. However, the migration of humpback whales along the New Zealand coast continues to be a higher risk period based on entanglement reports. The fishing gear type most recently described in entanglement reports is ‘cray’ (rock lobster).

Recent literature showed a breadth of work on entanglement mitigation and management. Approaches included gear-associated measures (gear modifications, acoustic deterrents and ropeless fishing), spatial and temporal closures, and investigations of whale ecology to understand and account for distribution and entanglement risks.

We identified a range of possible actions to build understanding, investigate and manage cetacean entanglement risks in New Zealand pot fisheries. These include improving reporting of entanglement events and pot soak times, growing knowledge of cetacean distribution (spatial and temporal), characterising gear in use in rock lobster and other pot fisheries, fostering the adoption of straightforward low/no cost mitigation approaches, and testing two technical mitigation methods (galvanic timed releases and rope segments) that are used internationally under local conditions.

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Glossary

ACE	Annual Catch Entitlement
BCO	Blue cod (*Parapercis colias*)
BMIS	Bycatch Management Information System
CELR	Catch Effort and Landing Return
COD	Central Observer Database
CRA	Rock lobster (*Jasus edwardsii*)
DOC	Department of Conservation
ER	Electronic Reporting
FMA	Fisheries Management Area
GWERN	Global Whale Entanglement Response Network
HAG	Hagfish (*Eptatretus cirrhatus*)
LIN	Ling (*Genypterus blacodes*)
MPI	Ministry for Primary Industries
NFPS	Non-fish Protected Species
NFPSCR	Non-fish/Protected Species Catch Return
PAD	Paddle crab (*Ovalipes catharus*)
PHC	Packhorse lobster (*Jasus verreauxi*)
QMA	Quota Management Area
WA	Western Australia

1. Introduction

Cetacean entanglements have occurred in pot (trap) fishing gear for decades (Rowe 2007; Read 2008; Hamilton & Baker 2019; Tremblay-Boyer & Berkenbusch 2020). Pot or trap fishing gear comprises a cage-type unit designed to sit on the sea floor and hold target catch for retrieval. Conventional pots are fitted with a rope and an attached buoy (known as a buoy line or downline, among other names) that marks the pot position at the sea surface. Cetaceans may become entangled with these ropes while moving through fished areas. Entanglements can result in injuries and mortalities, making these interactions an issue for both animal welfare and potentially cetacean population persistence (Perrin et al. 1994; Reeves et al. 2013; Kraus et al. 2016). Further, the high likelihood of cryptic entanglements and associated mortalities means the true extent of mortalities and potential for impacts on populations are difficult to determine (Pace et al. 2020). Pots and traps have different design characteristics around the world. For this report, we take an inclusive approach to considering pot and trap gear, with the buoy lines deployed from such gear being the key characteristic of the fishing method that creates entanglement risk.

Approaches to reducing cetacean interactions with pot fishing gear, and the associated individual or population impacts, include gear modifications, spatial/temporal management of interactions, and interventions in entanglement events to release the entangled animal(s) (Rowe 2007; Berkenbusch et al. 2013; Robbins et al. 2015; Hamilton & Baker 2019; Tremblay-Boyer & Berkenbusch 2020). Determining the efficacy of mitigation measures designed to reduce entanglements may be difficult, e.g., if interactions occur at low rates and comparisons of the extent of interaction with and without mitigation in place are required. Implementing disentanglement procedures is also not straightforward, given entangled animals are not necessarily stationary. Further, there are operational and technical challenges, e.g. health and safety of disentanglement teams, and implementation of disentanglement methods on the water (NOAA 2018; Edwards 2019[4]).

Cetacean entanglements with pot fishing gear in New Zealand waters have been documented since 1980 (Berkenbusch et al. 2013; Laverick et al. 2017). Reports are more common in recent years, with 63% recorded through 2010 – 2020, and an average rate of 4.7 records per year. In New Zealand, attempting disentanglement has been the main approach to addressing entanglements of large cetaceans. New Zealand is involved in the Global Whale Entanglement Response Network (GWERN) and, as the responsible government agency, the Department of Conservation has a Standard Operating Procedure setting out disentanglement protocols and training requirements. Industry bodies have also developed guidance for commercial pot fishers targeting rock lobster (*Jasus edwardsii*) and ling (*Genypterus blacodes*), on how to reduce the risk of cetacean entanglements with fishing gear (Deepwater Group Ltd 2020; NZ RLIC 2022). The 'WhaleSafe' guide developed by the New Zealand Rock Lobster Industry Council to disseminate information on whale identification, reporting requirements, and approaches to mitigation, is now in its third edition (NZ RLIC 2022).

Previous work characterising cetacean entanglements with fishing gear in New Zealand waters reported that most recorded large whale entanglements involved gear identified as originating in the rock lobster fishery (54% of 39 large whale entanglements recorded 1984 - 2017) (Laverick et al. 2017). Gear associated with another 10% of entanglements was reported as likely to be used for rock lobster fishing. Commercial and recreational gear was not always distinguished. Almost all large whale entanglement events with rock lobster gear, for which

[4] https://iwc.int/management-and-conservation/entanglement/best-practice-guidelines-for-entanglement-responde [Accessed 1 May 2022]

locations are identifiable by latitude and longitude, were reported from the east coast of the South Island (Banks Peninsula northwards) and the east coast of the North Island (Bay of Plenty to the Hauraki Gulf). In the South Island, humpback whale *(Megaptera novaeangliae)* entanglements prevailed. By contrast, orca *(Orcinus orca)* entanglements were most common in the North Island locales (Laverick et al. 2017).

Populations of some large cetaceans appear to be undergoing post-whaling recovery in New Zealand waters, e.g., humpback (*Megaptera novaeangliae*) and southern right whales (*Eubalaena australis*) (Jackson et al. 2016; Gibbs et al. 2018), while orca (*Orcinus orca*) may be declining (Baker et al. 2019). Considered together, the prevalence of pot fishing gear among entanglement reports, increasing populations of some whale species, and the likelihood of ongoing spatial and temporal overlap between pot fisheries and entangling species, suggest that entanglement incidents have the potential to increase. From a fishery perspective and beyond any impacts on the entangling species, entanglements are an issue for the social licence of the fisheries with which they are associated (Hodgson et al. 2019; How et al. 2020a, 2020b).

In this project, we:

- Update the previous analysis (Laverick et al. 2017) of cetacean entanglements and catch and effort in the New Zealand pot fishery;
- Review recent developments in the management and mitigation of cetacean entanglements with pot/trap fishing gear;
- Report on the outcomes of a workshop conducted with rock lobster fishers, gear developers, fishery and wildlife managers, and researchers from international pot/trap fisheries in which large cetacean entanglements occur; and,
- Using these inputs, set out proposed next steps to progress the management and mitigation of large cetacean entanglement risks in New Zealand pot fisheries.

2. Project approach

2.1 Fishery data

2.1.1 Pot fishery catch and effort data

Catch and effort data for all New Zealand potting events from statutory fisher reporting were provided by the Ministry for Primary Industries (MPI) as REPLOG13962.

Data were provided for all Fishery Management Areas in the New Zealand Exclusive Economic Zone, for all years from 1 October 1989 through 30 December 2021, including:

- Fields from statutory catch and effort reporting (Catch Effort and Landing Return (CELR) and Electronic Reporting (ER)):
    - CELR data: vessel ID, event start and end dates, fishing event type, pot lifts, statistical area (a generic New Zealand Fisheries Statistical Area or a stock-specific statistical area for rock lobster (CRA)), and catch records (species codes and greenweight caught).
    - ER data: trip ID, vessel ID, trip start and end dates/times/positions, target species code, pot lifts, soak time (the estimated average duration that pots are submerged during a fishing event), and fine-scale start and end positions, catch records (species code, greenweight caught), presence of non-fish protected species (NFPS) events, and any Amendment reasons and Notes associated with these records.

- All commercial fisher reports of cetacean interactions with pot fishing events, as made using the Non-fish/Protected Species Catch Return (NFPSCR) and, superseding that form, ER:
    - NFPSCR fields: date, time, form number from CELR (or other linking field), species code, number uninjured/alive/dead, related location information for the NFPS events (e.g., statistical areas and/or latitude and longitude, as available).
    - ER NFPS catch reports for all whale and dolphin interactions with pot fishing, linked or able to be linked with fishing events. Fields requested were: trip ID, vessel ID, NFPS catch date/time, fish catch event ID, NFPS catch location, amendment reason, notes, species code, number injured/uninjured/dead /decomposing.

Data processing was carried out in R (R core team 2019). Records were allocated to target species subsets, either rock lobster (*Jasus edwardsii*; CRA), packhorse lobster (*Jasus verreauxi*; PHC), ling (*Genypterus blacodes*; LIN), blue cod (*Parapercis colias*; BCO), paddle crab (*Ovalipes catharus*; PAD), hagfish (*Eptatretus cirrhatus*; HAG), or all other target species combined (Other). Calendar and fishing year variables were inferred from the start date of the event recorded. Latitude and longitude (where recorded) were groomed to remove outliers and recode variables incorrectly recorded as longitudes East and latitudes North. Effort was classified as either number of pot lifts per day (CELR records) or total number of reported pot lifts (ER data).

Records provided for October, November, and December 2021 were considered likely to be incomplete with data submission and processing underway for those months at the time of our data request. For example, 2,795 records were available for September 2021 compared to 845 for October, one for November and 26 for December. Therefore, we used records available through to 30 September 2021 to prepare figures presented in this report.

Fishery catch and effort data are presented in calendar years.

Statistical area classifications were checked for errors and recoded to ensure these were recorded as either generic statistical areas (001-801) or CRA statistical areas (901-939). Statistical areas were also checked against latitude/longitude records where these were available, and corrected as required. Records with fields that contained obvious errors were not deleted, but the associated variable was set to "missing', and included, where possible, in the analyses.

Using the ER data fields of the number of pot lifts and hours of soak time, we created a combined value denoted "rope hours". All target species were considered together, providing total rope hours. This value provides in indication of entanglement risk in time and space, analogous to the rope days metric developed in How et al. (2020b). Because soak time is a data field collected with the introduction of ER, the rope hours metric is calculated for 2019 through 30 September 2021.

2.1.2 Observer data

Government fisheries observers deployed on commercial fishing vessels are tasked with recording interactions of protected species with the fishing operations monitored, including cetacean entanglements. Observer records of cetacean interactions with pot fishing gear were requested from MPI, where these records are stored electronically (i.e. in the Central Observer Database (COD)), including date, time, location, fishery, fishing gear, cetacean species caught, life and injury statuses, and any comments. The timeframe for this request was 1 October 1989 through 11 October 2021. No observed records were received.

2.2 Cetacean entanglement events

Information on entanglements held by DOC was requested, from 1980 to 31 December 2021. Entanglement records provided by DOC to the project team were extracted from:

- The New Zealand Whale Strandings Database (records filtered by 'Entanglement' in the 'Contributing Factor' field)
- The Hector's and Māui Dolphin Incident Database (records filtered by 'Entanglement' in the 'Observation Type' field)
- The Large Mammal Entanglement Database (file: DOCDM-883260).

Forty-one records were provided from the New Zealand Whale Strandings Database, collected from 02/07/1980 to 22/05/2020. Reported fields included the number of animals per incident, location information (latitude and longitude, description of location, region), life status and condition of the animal, and comments. These fields were complete for all records.

Three entanglement records were provided from the Hector's and Māui Dolphin Incident Database (from between 16/01/1989 and 02/08/2004). All three records included date, location information (place name or description, and latitude and longitude), and a brief description of the event.

The Large Mammal Entanglement Database extract included 35 records, collected from 2000 to 28/11/2014. Locations were specified by place name, and had variable specificity (e.g. identifying a specific location such as Sharks Tooth, Kaikoura, or a more general area such as the Bay of Islands). Sixteen records had specific dates attached, while the remainder were documented by year only. Comments were entered in a free text field for 15 records (e.g. fishing gear type).

Four additional records were provided by the former DOC Disentanglement team leader (R. Chappell, pers. comm.) and the project team located one more record in the media[5].

After removing duplicate records and adding three bycatch records (of four animals) identified in fisher-reported data provided by MPI, a final set of 82 entanglement records was used for the project. Entanglement records were not interpreted in any way, with categorisation of the gear type or other details of the entanglement taken as stated in the record. Verification of the cetacean species and the identifications of fishing gear reported was also not possible. Entanglement records were tabulated and mapped based on the location information provided. A summary of the entanglement records is provided at Appendix 1: Summary of cetacean entanglement records.

2.3 Cetacean entanglement mitigation in pot fisheries

We used internet search engines (Google, Google Scholar) to conduct a literature and broader information search to identify work undertaken on the management and mitigation of cetacean entanglements in fishing gear since the publication of the most recent reviews of marine mammal bycatch mitigation (Hamilton & Baker 2019; Tremblay-Boyer & Berkenbusch 2020). Key words and wildcard search terms (such as bycatch, bycaught, pot, trap, whale, dolphin, cetacean, mitig*, entangle*, fisher*) were used in various combinations with Boolean operators. Searches of Google Scholar were timebound, covering 2019 – 1 March 2022. We also searched online repositories for mitigation information, such as the Bycatch Management Information System (BMIS, bycatch.org).

From any publications identified using these search methods, a 'snowballing' technique was employed to find additional publications. This involved examining any reference in the

[5] Video: Hector's dolphin entangled in cray pot line rescued by boaties (1news.co.nz) [Accessed 11 April 2022]

publications that met the criteria above and accessing those relevant publications. This was further applied to all new publications identified, to ensure a thorough search was completed.

Relevant work identified covered four broad approaches to understanding and addressing entanglement risks. These were gear modification, spatial and/or temporal risk management, acoustic deterrents, and ecological impacts. We present a review of these publications using the following categories:

- Identification and characterisation of the entanglement issue
- Processes for identification of mitigation options
- Processes for evaluation of mitigation options, and
- Evaluation of mitigation options.

We note that these steps could be used as a framework for continuing to progress work on whale entanglements in New Zealand fisheries.

2.4 Workshop

We convened an online workshop on 22 March 2022 with rock lobster fishery participants, industry representatives, New Zealand disentanglement network experts, and international practitioners working on disentanglement, gear modifications, and in pot fisheries where there are whale entanglement risks (Appendix 2: Workshop participants). The purposes of the workshop were:

- To share information among pot fishery participants and DOC, to better understand entanglement risks and issues
- To consider possible next steps and appropriate actions, and
- To get ahead of the entanglement issue and drive it forward with meaningful industry involvement.

The workshop included discussions of:

- Recorded whale entanglements in New Zealand
- Spatial and temporal patterns in pot fishing effort (pot lifts, soak time)
- International responses to entanglement risks and issues
- Current actions that may reduce entanglement risks in the rock lobster fishery
- Potential future actions that may be appropriate for pot fisheries in New Zealand, and
- Knowledge gaps relevant to managing entanglement issues and risks.

Four presentations were given by international participants. A workshop report was prepared and circulated to participants after the session, to provide a record of the discussion and summarise conclusions as presented below.

3. Results

3.1 Commercial pot fishery catch and effort

3.1.1 Overview

Cetacean entanglement risks are created by the overlap of these animals with pot fisheries in space and time, and the number of buoy lines in the water where overlap occurs (affecting encounter probability). In the sections that follow, we present summary fishery information to support a consideration of entanglement risk in space and time in New Zealand waters. We focus on the period since the work of Laverick et al. (2017), while also presenting some longer time series information for context, e.g., to illustrate changes in the amount and distribution of total pot fishing effort over time.

Pot fishing effort information reported by fishers on CELR forms included the number of pot lifts per day, in a statistical area (Fisheries Reporting Regulations 2001; Research & Data Reporting Group 2010). Following the adoption of ER in 2019, the spatial resolution of fishing catch and effort information has increased significantly. Reporting the latitude and longitude of pot lifts is now required, to variable spatial scales. For example, a separate catch report is required when a rock lobster pot is lifted more than 10 nm from the first pot lifted. For blue cod pots, this distance is 2 nm. For all other target species and strings of pots, this distance is 1 nm (Fisheries New Zealand 2021).

In New Zealand waters, pot fishing occurs in all Fisheries Management Areas (FMAs) except FMA 10 (Kermadec). The amount of pot fishing effort reported has declined significantly from 1990 to 2021 (Figure 1). For example, in the 1992 fishing year, pot lifts reported from Fishery Management Area (FMA) 2 alone approached 2,000,000. In 2013, this had dropped by 75%. Comparable reductions in the number of pot lifts have not occurred across all regions (Figure 1). However, the total annual number of pot lifts around New Zealand has decreased from almost 5 million in 1990, to less than 2 million in 2018. Reduced pot fishing effort targeting rock lobster drives this trend. On average, rock lobster pot lifts comprised 90% of all pot lifts, from 1 January 1990 to 30 September 2021, with comparatively very small amounts of pot fishing effort targeting blue cod, packhorse lobster, ling, paddle crab and hagfish (Figure 2).

Reporting soak time (average soak time of the pots lifted during a fishing event) was newly required under ER (Fisheries Reporting Regulations 2001; Fisheries New Zealand 2021). Across all target species and regions, most reported soak times were less than 100 hours. Some records of soak times of multiple hundreds of hours also exist among the data (Figure 3). The very long soak times in the dataset require investigation and some records may be spurious. However, fishing practices are variable and at what point any cut-off should be introduced (with soak times above that considered invalid and discarded) requires further exploration.

Note: To comply with the requirements set by the Ministry for Primary Industries for the public release of fishery data, Figure 16, Figure 19, Figure 22 and Figure 25 require redaction from this report.

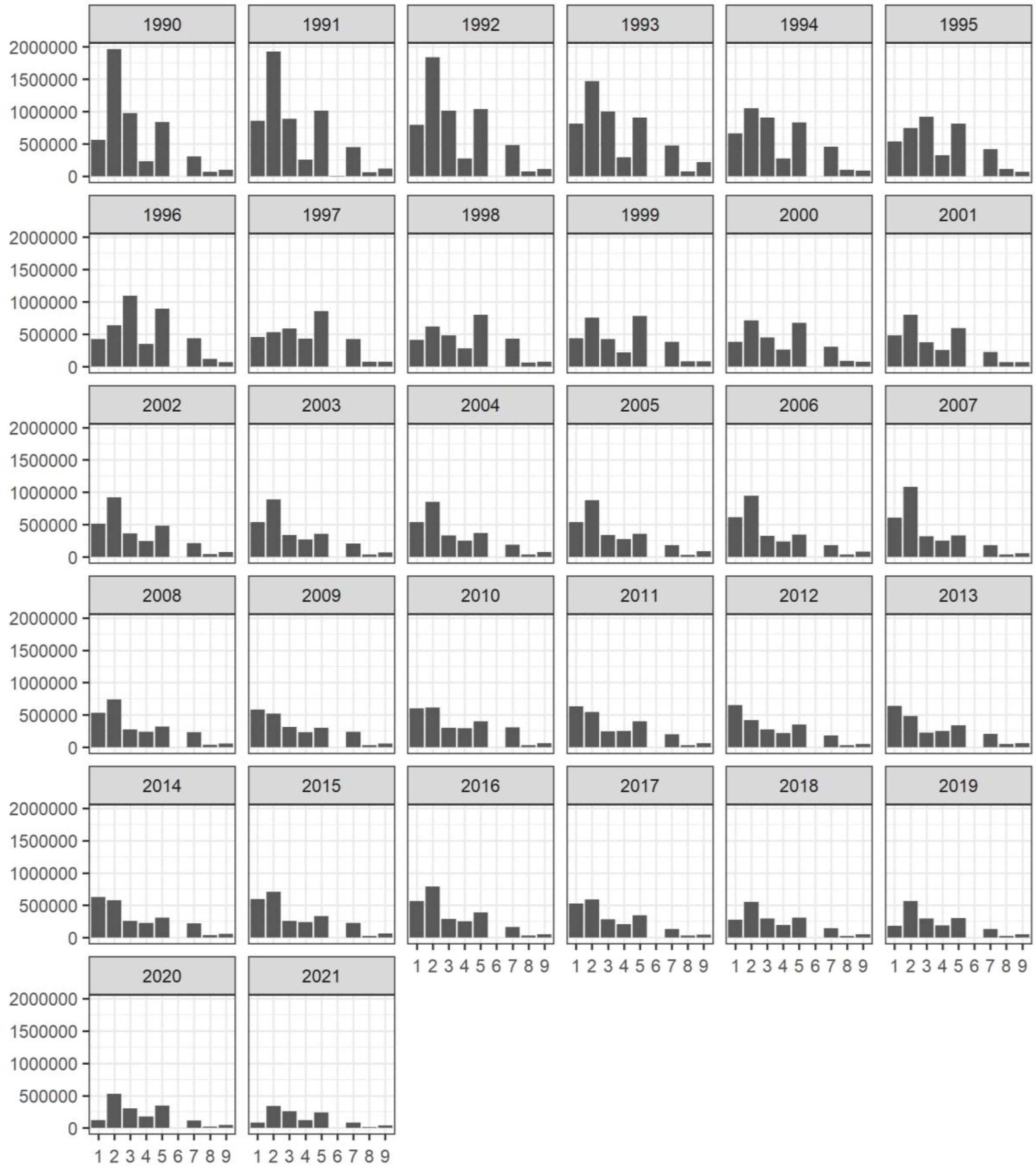

Figure 1. Annual fisher-reported pot fishing effort (total number of pot lifts) for all target species 1 January 1990 – 30 September 2021, by region of New Zealand (numbered 1 – 9). Regions approximate New Zealand Fisheries Management Areas (Appendix 3).

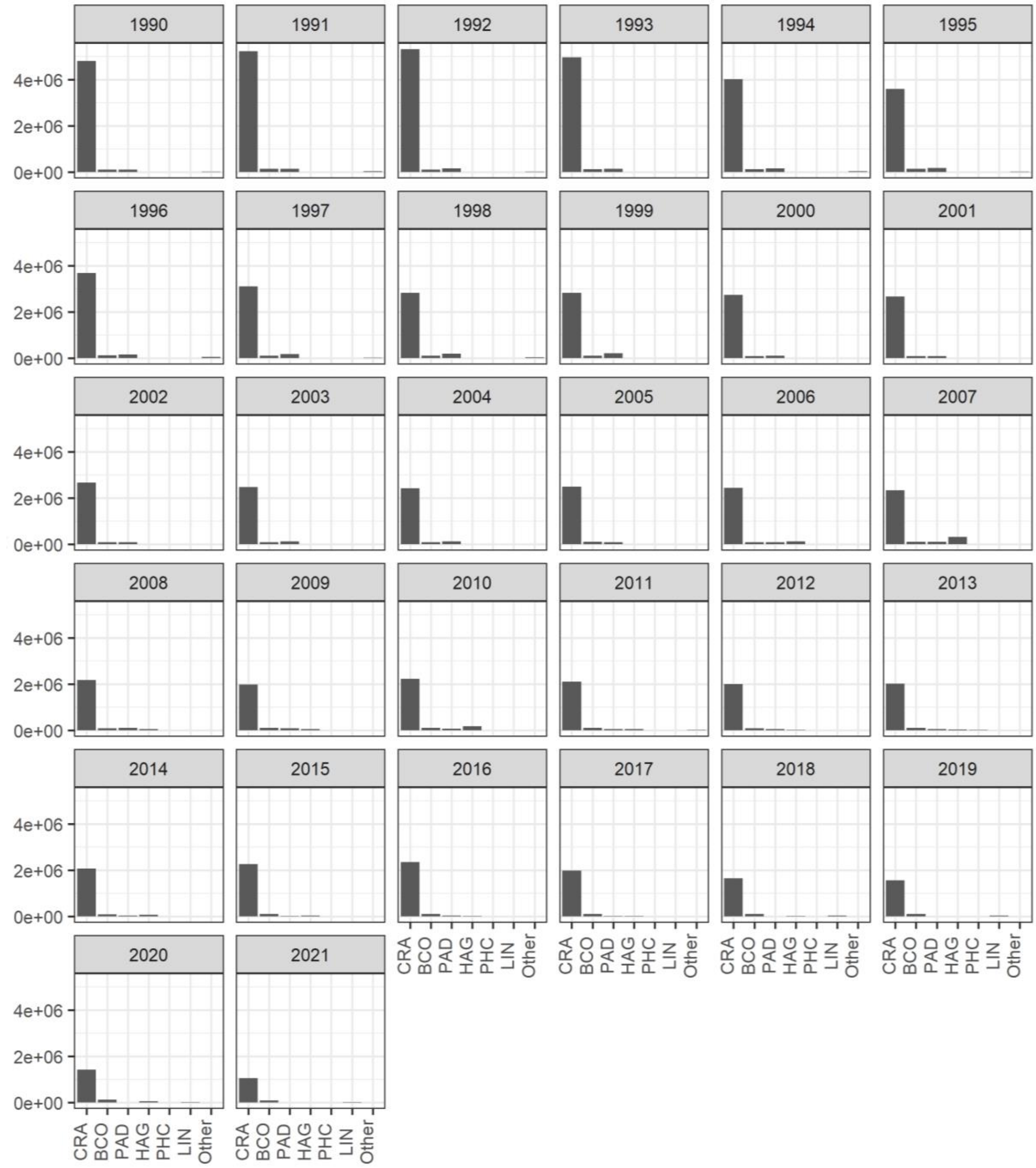

*Figure 2. Annual fisher-reported pot fishing effort (total number of pot lifts) 1 January 1990 – 30 September 2021, by target species. Species are rock lobster (*Jasus edwardsii*; CRA), blue cod (*Parapercis colias*; BCO), paddle crab (*Ovalipes catharus*; PAD), hagfish (*Eptatretus cirrhatus*; HAG), packhorse lobster (*Jasus verreauxi*; PHC), ling (*Genypterus blacodes*; LIN), and all other target species (Other).*

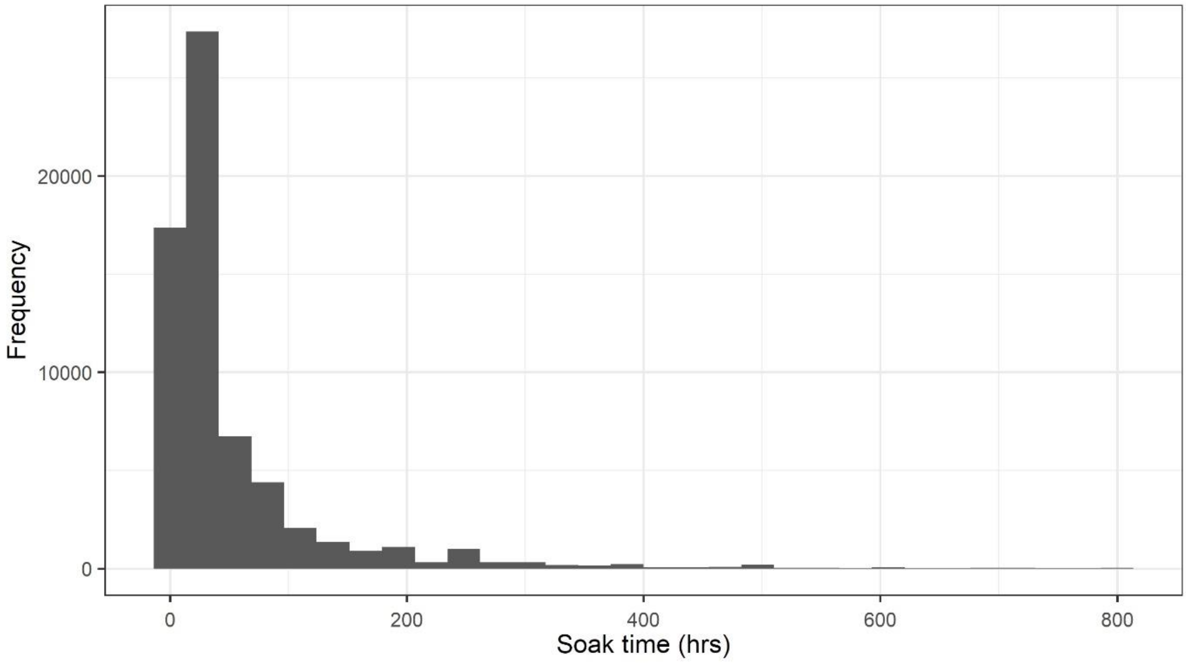

Figure 3. Fisher-reported pot soak times for all target species, 1 January 2019 – 30 September 2021.

3.1.2 Rock lobster

Pot fishing effort targeting rock lobster occurs around the New Zealand coast (Figure 4, Figure 5). Since 2019, the highest number of pot lifts was reported from around the top of the South/bottom of the North Islands, and the Chatham Islands. However, pockets of higher density fishing effort also occur along the coast of both main islands (Figure 4). Fishing effort varies throughout the year in different areas. In the last five years, peaks in effort are evident in rock lobster Quota Management Area (QMA) CRA 4 in January, CRA 5 in May and CRA 8 in April/May and September (Figure 5), with broadly commensurate peaks in catch in these areas (Figure 6). In general, longer total soak times are reported from areas where more fishing effort occurs (Figure 7).

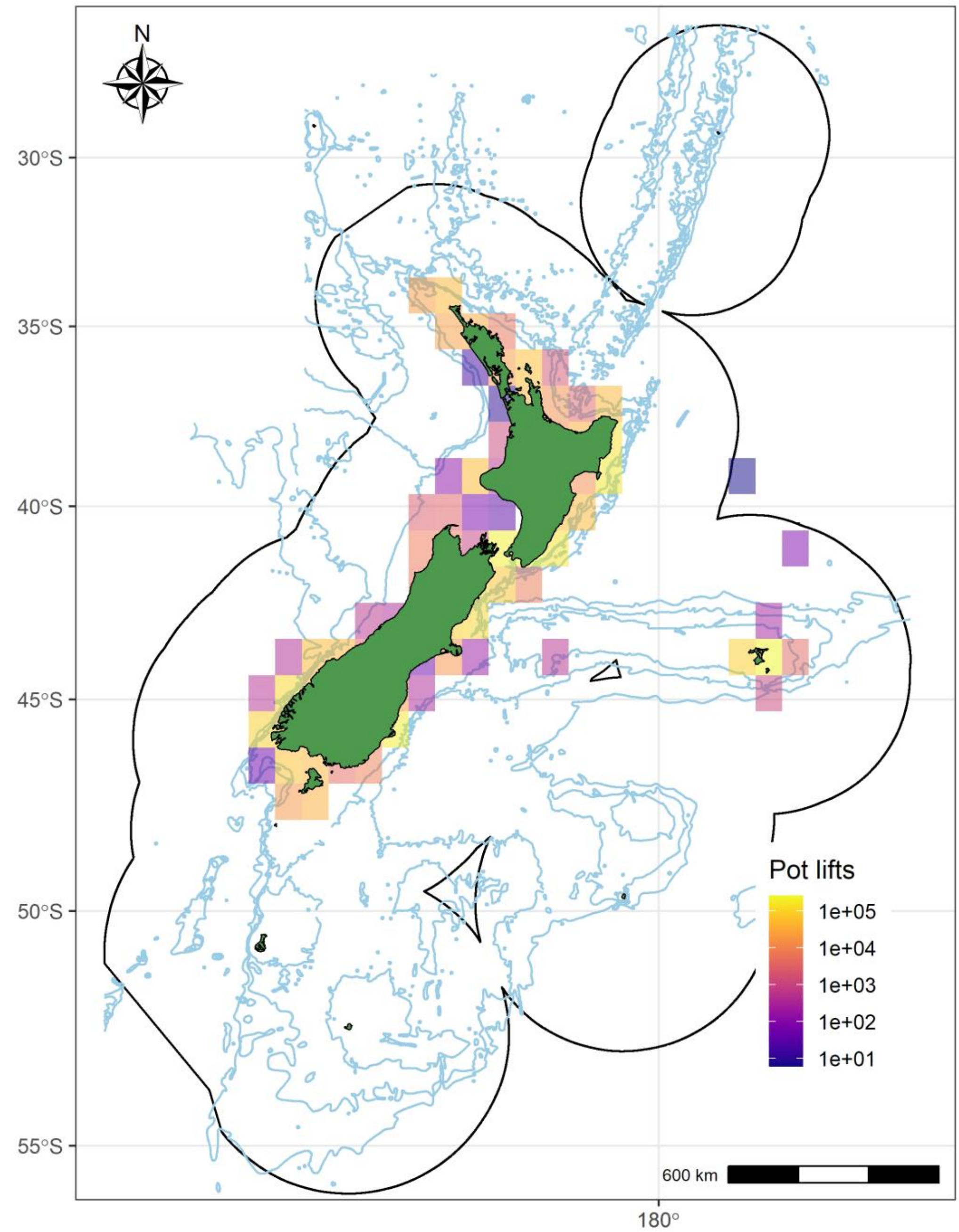

*Figure 4. Fisher-reported pot fishing effort (total number of pot lifts) targeting rock lobster (*Jasus edwardsii*), 1 January 2019 – 30 September 2021. Pot lift density is shown in 1-degree squares.*

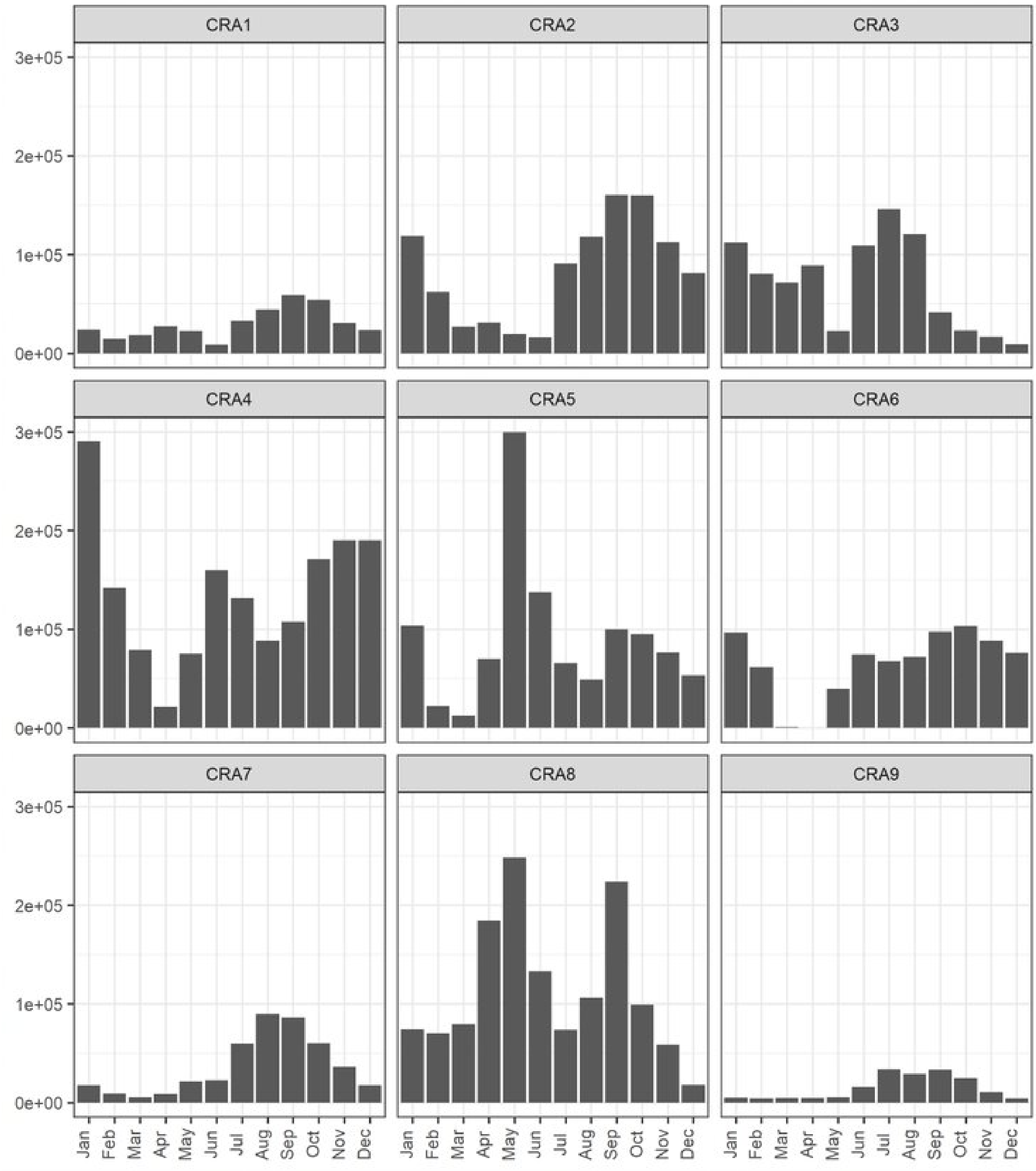

*Figure 5. Monthly fisher-reported pot fishing effort (total number of pot lifts) targeting rock lobster (*Jasus edwardsii*, CRA), 1 January 2017 – 30 September 2021. Pot lifts are shown by CRA Quota Management Areas.*

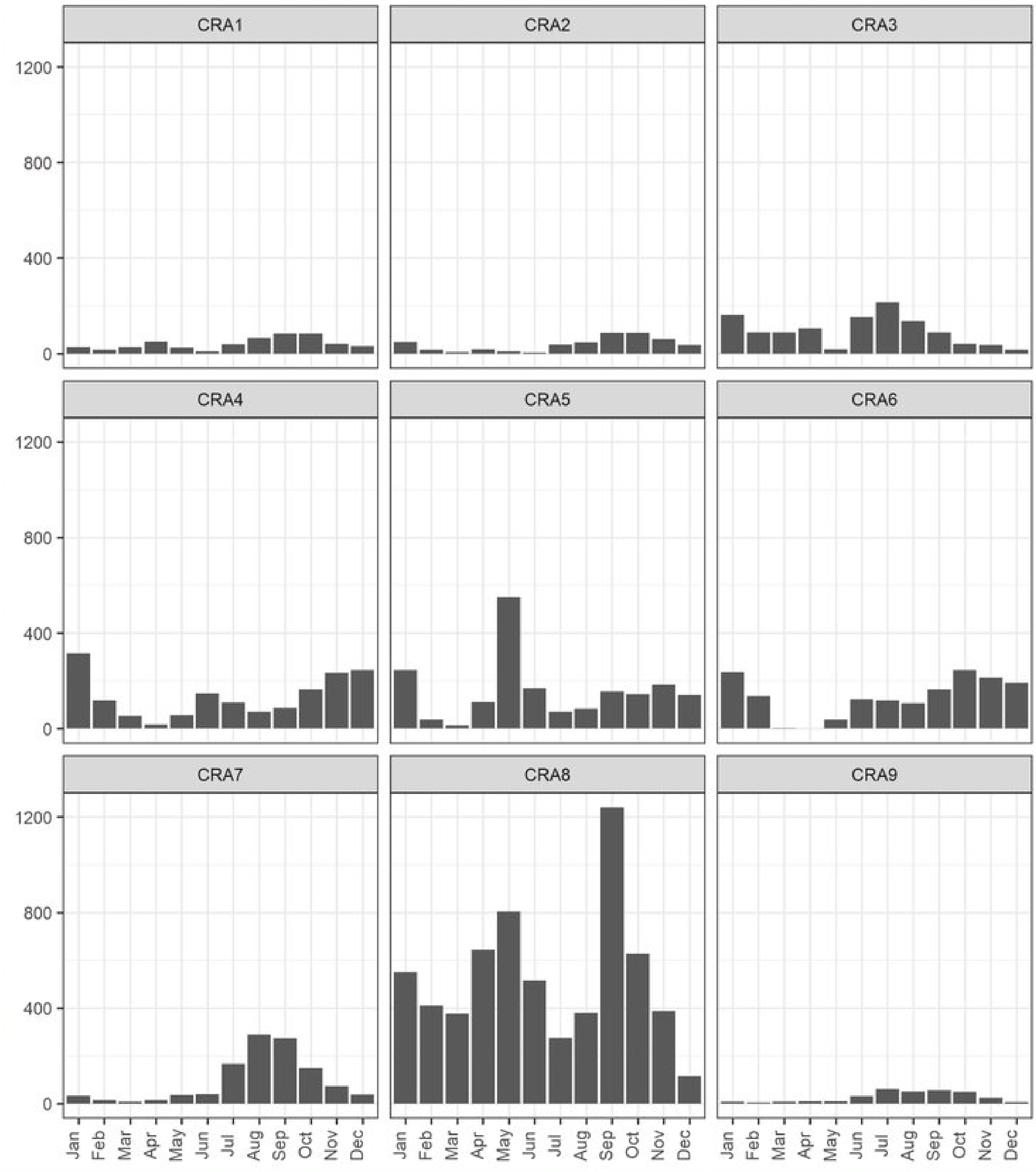

*Figure 6. Total monthly fisher-reported pot fishing catch (t) of rock lobster (*Jasus edwardsii, CRA*), 1 January 2017 – 30 September 2021, shown by CRA Quota Management Areas.*

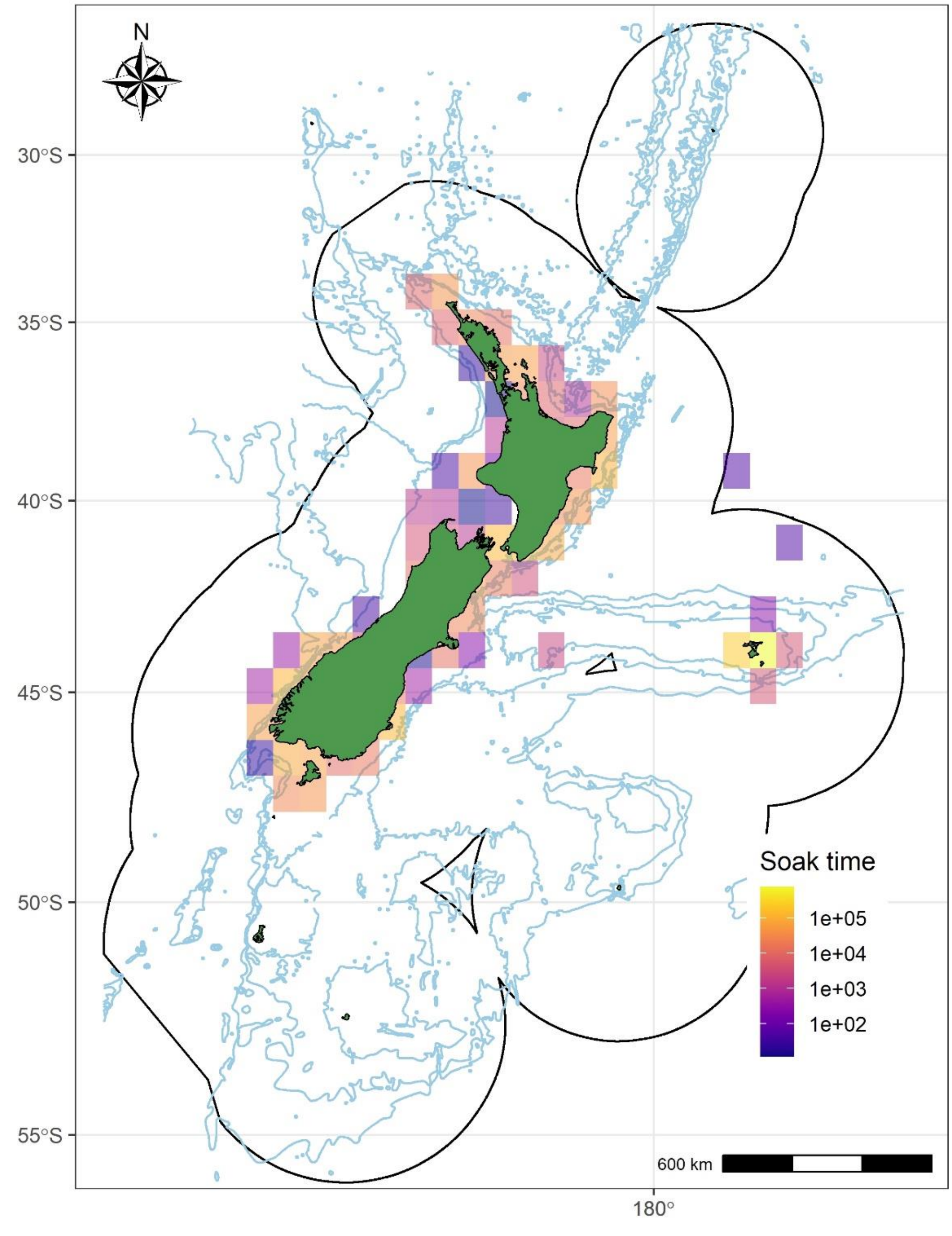

*Figure 7. Fisher-reported soak time (total number of hours) for pot fishing targeting rock lobster (*Jasus edwardsii*), 1 January 2019 – 30 September 2021, by one-degree squares.*

3.1.3 Packhorse lobster

Pot fishing effort (total pot lifts) targeting packhorse lobster is concentrated in the north of New Zealand's North Island (Figure 8). Since 2017, fishing effort has been concentrated outside the winter months within the boundaries of QMA CRA 1, with reported catches peaking in September (Figure 9, Figure 10). In the area comprising CRA 2, fishing occurs year-round with effort peaking in April. Again, catches are highest in September (Figure 10).

There are anecdotal reports of fishers using pot strings to target packhorse lobster (also known as pot/trap longlines, in which multiple pots are deployed along a single rope line, to which a buoy is attached at the sea surface). Use of pot strings was described as associated with sandy substrates on which packhorse pots are set (discussed at the workshop undertaken for this project). For rock lobster fishing, pot strings were not considered a viable method for fishing on rocky ground (M. Edwards, pers. comm.). Relevant to the cetacean entanglement context, the pot string fishing method reduces the number of vertical rope lines in the water, as each individual pot is not linked to a vertical line.

Total soak times varied across an order of magnitude among pot fishing effort targeting packhorse (Figure 11).

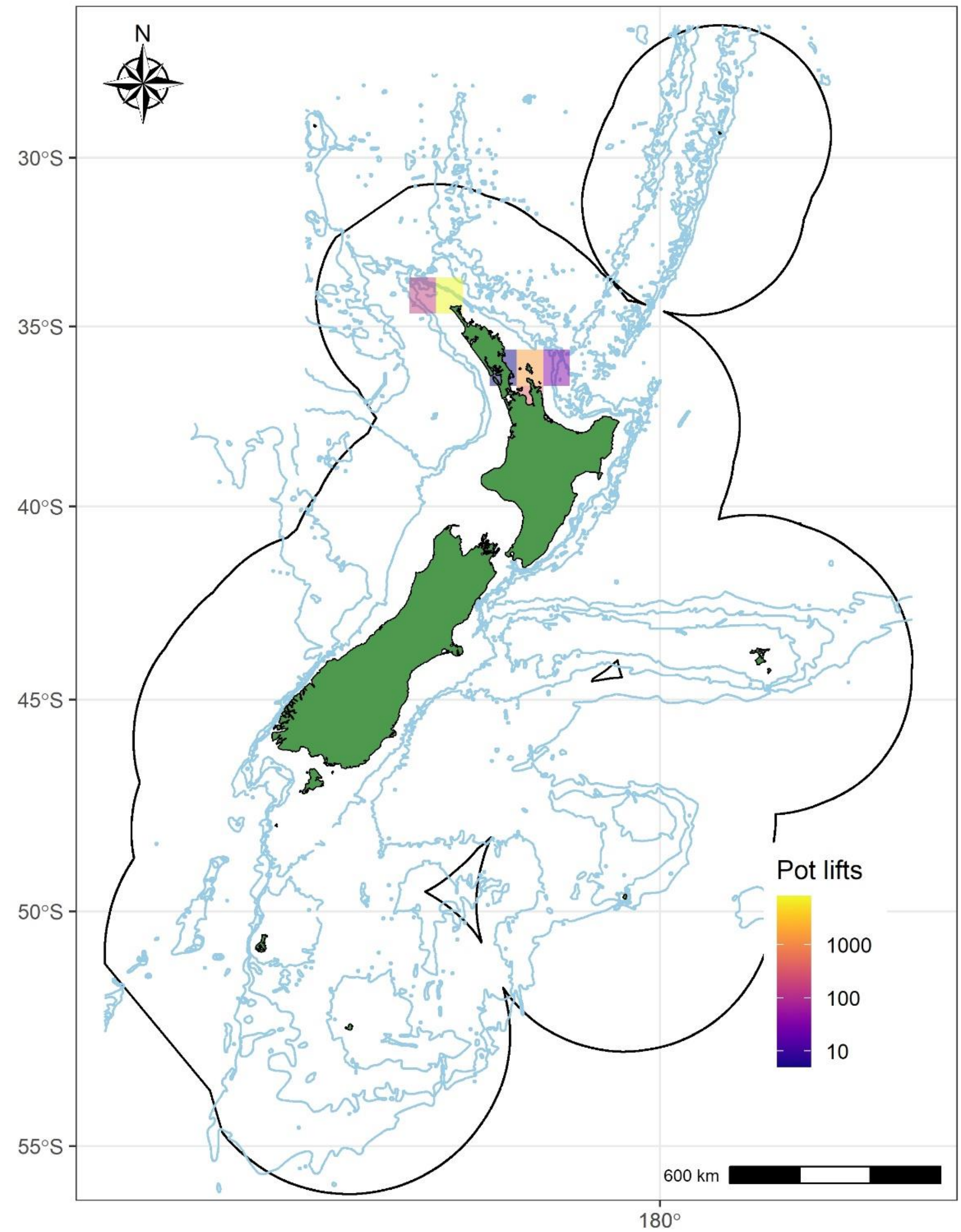

*Figure 8. Fisher-reported pot fishing effort (total number of pot lifts) targeting packhorse lobster (*Jasus verreauxi*), 1 January 2019 – 30 September 2021. Pot lift density is shown in 1-degree squares.*

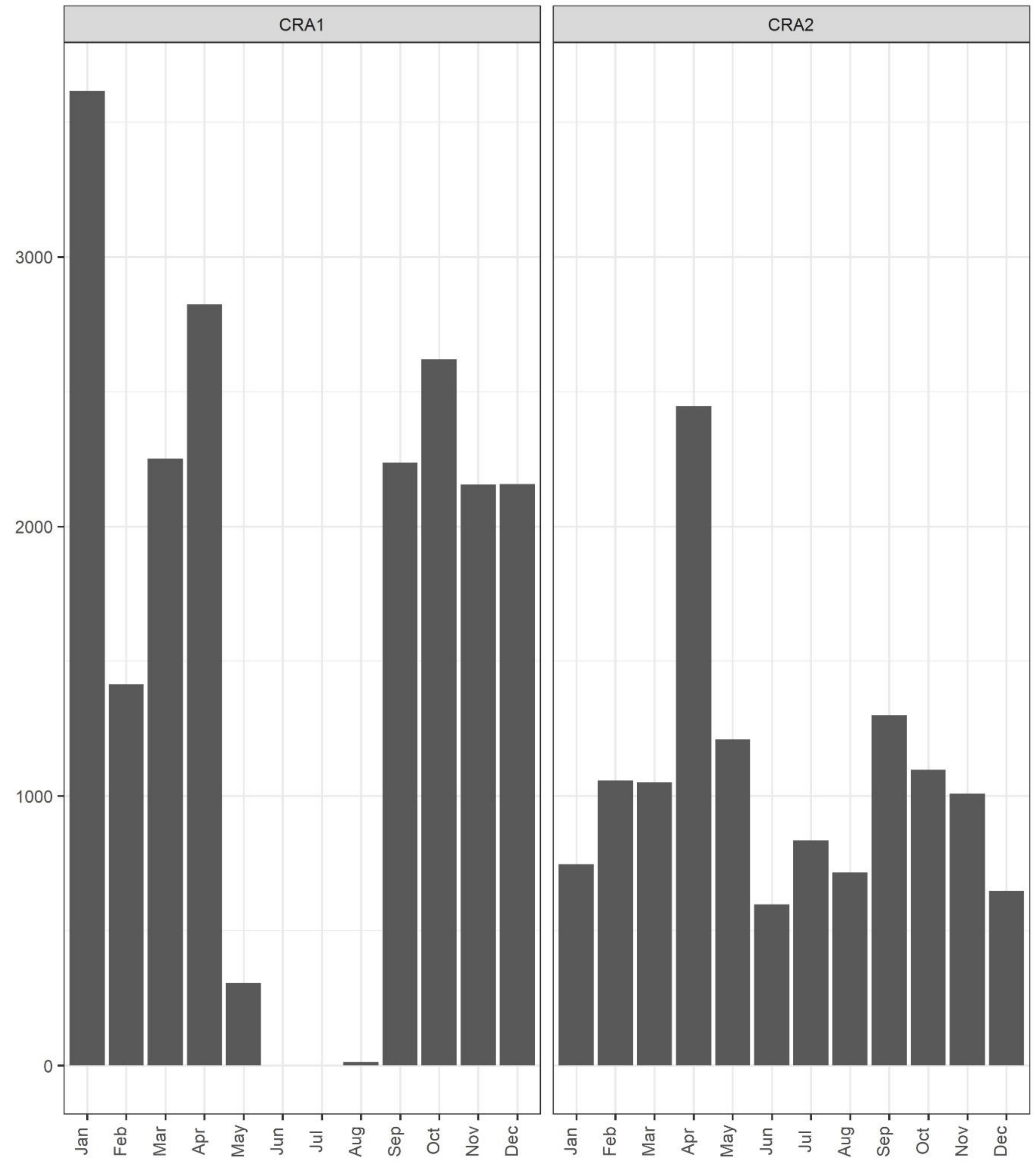

*Figure 9. Monthly fisher-reported pot fishing effort (total number of pot lifts) targeting packhorse lobster (*Jasus verreauxi*), 1 January 2017 – 30 September 2021. Pot lifts are shown by rock lobster (*J. edwardsii*, CRA) Quota Management Areas. (New Zealand waters comprise a single packhorse lobster Quota Management Area).*

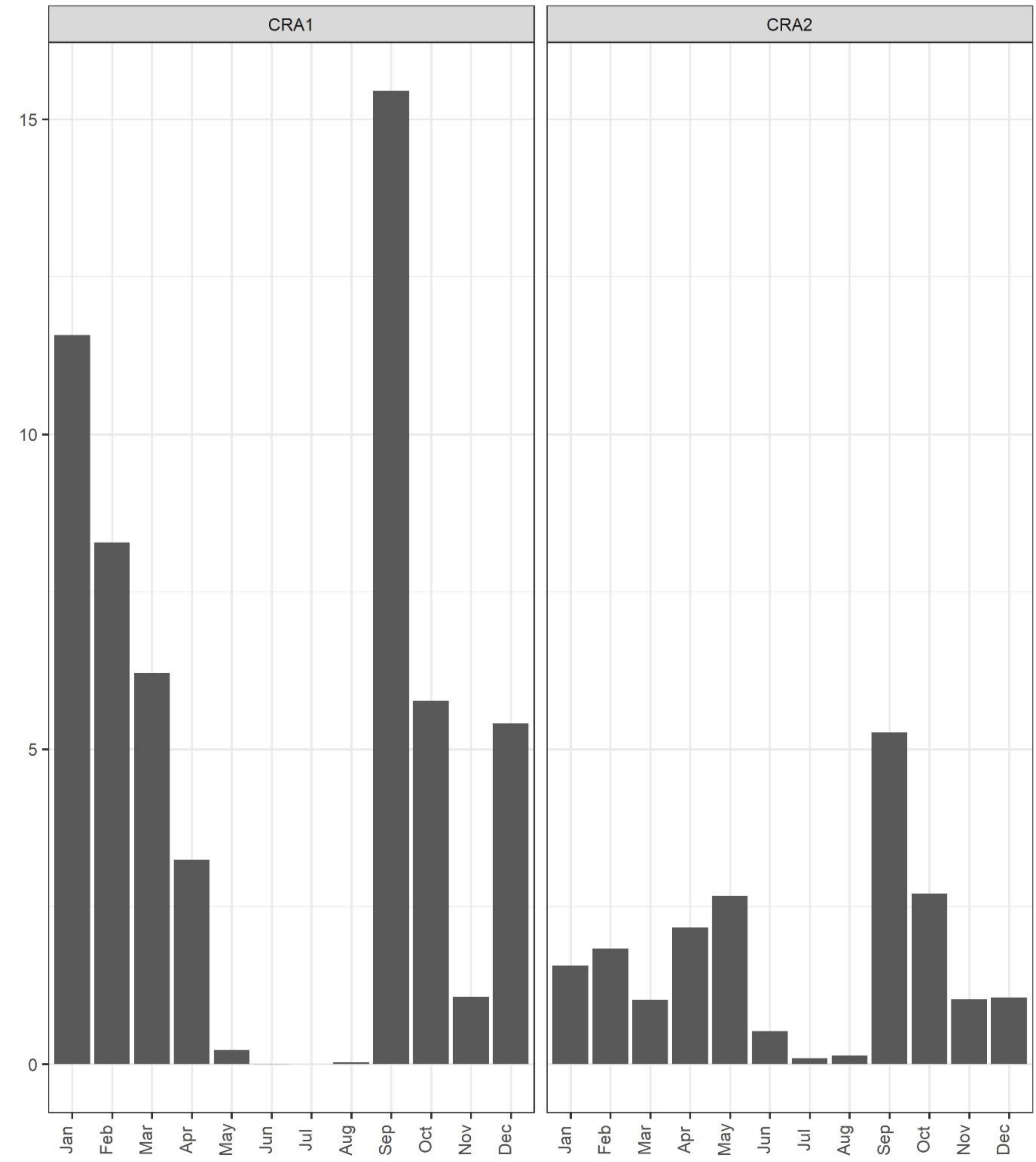

*Figure 10. Total monthly fisher-reported catch of packhorse lobster (*Jasus verreauxi*), 1 January 2017 – 30 September 2021. Catch is shown by rock lobster (*J. edwardsii*, CRA) Quota Management Areas. (New Zealand waters comprise a single packhorse lobster Quota Management Area).*

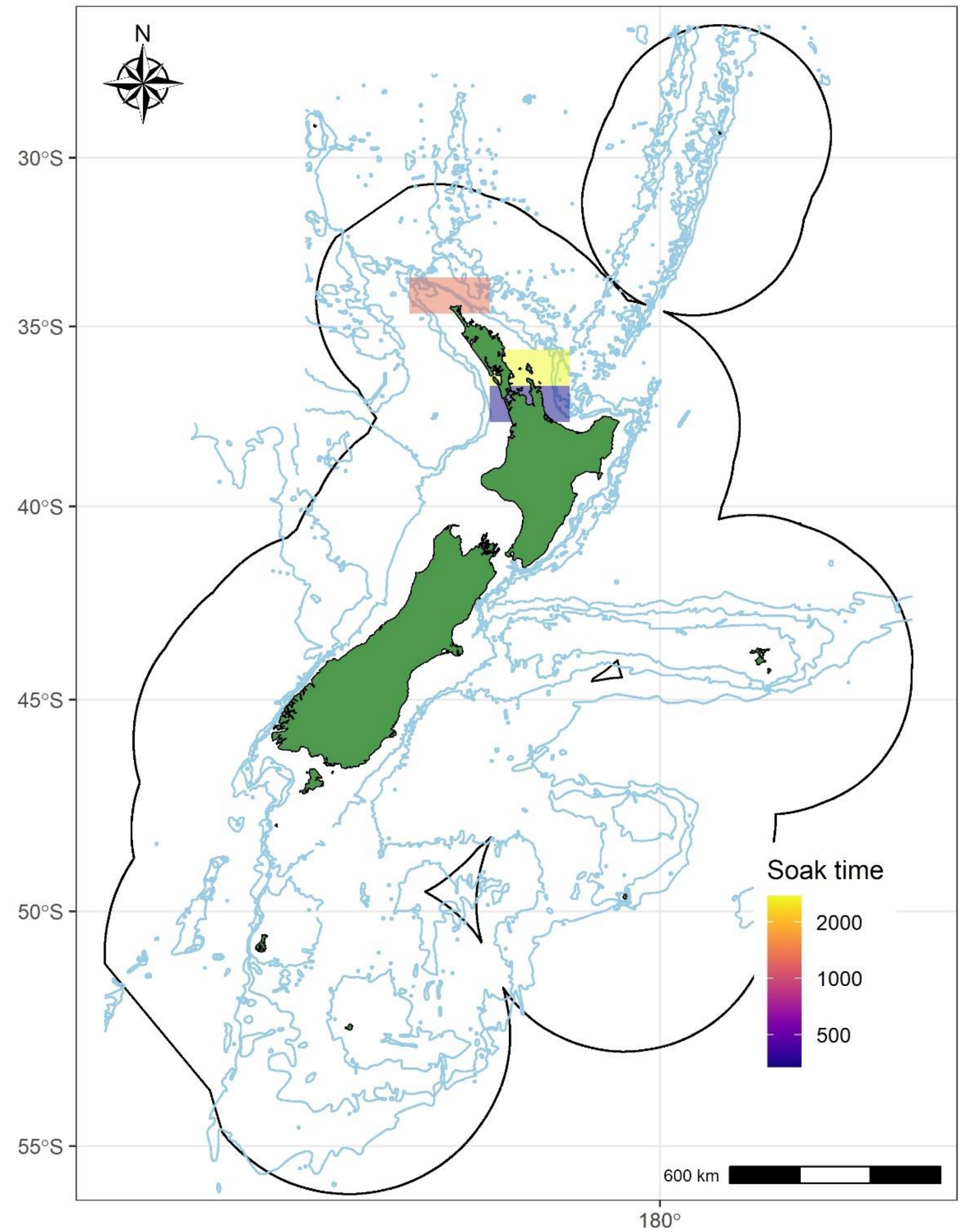

*Figure 11. Fisher-reported soak time (total number of hours) for pot fishing targeting packhorse lobster (*Jasus verreauxi*), 1 January 2019 – 30 September 2021, by one-degree squares.*

3.1.4 Blue cod

Most pot fishing effort targeting blue cod was reported from southern New Zealand and the Chatham Islands (Figure 12). Fishing effort in FMA 4 tended to increase through the winter, while in FMA 5 this varied throughout the year. Effort in other FMAs was significantly lower (Figure 13). Broadly reflecting effort trends, catches were highest in FMA 4 in the winter months and more variable through the year in FMA 5 (Figure 13, Figure 14). Total pot soak time was highest around Foveaux Strait/Stewart Island (Figure 15).

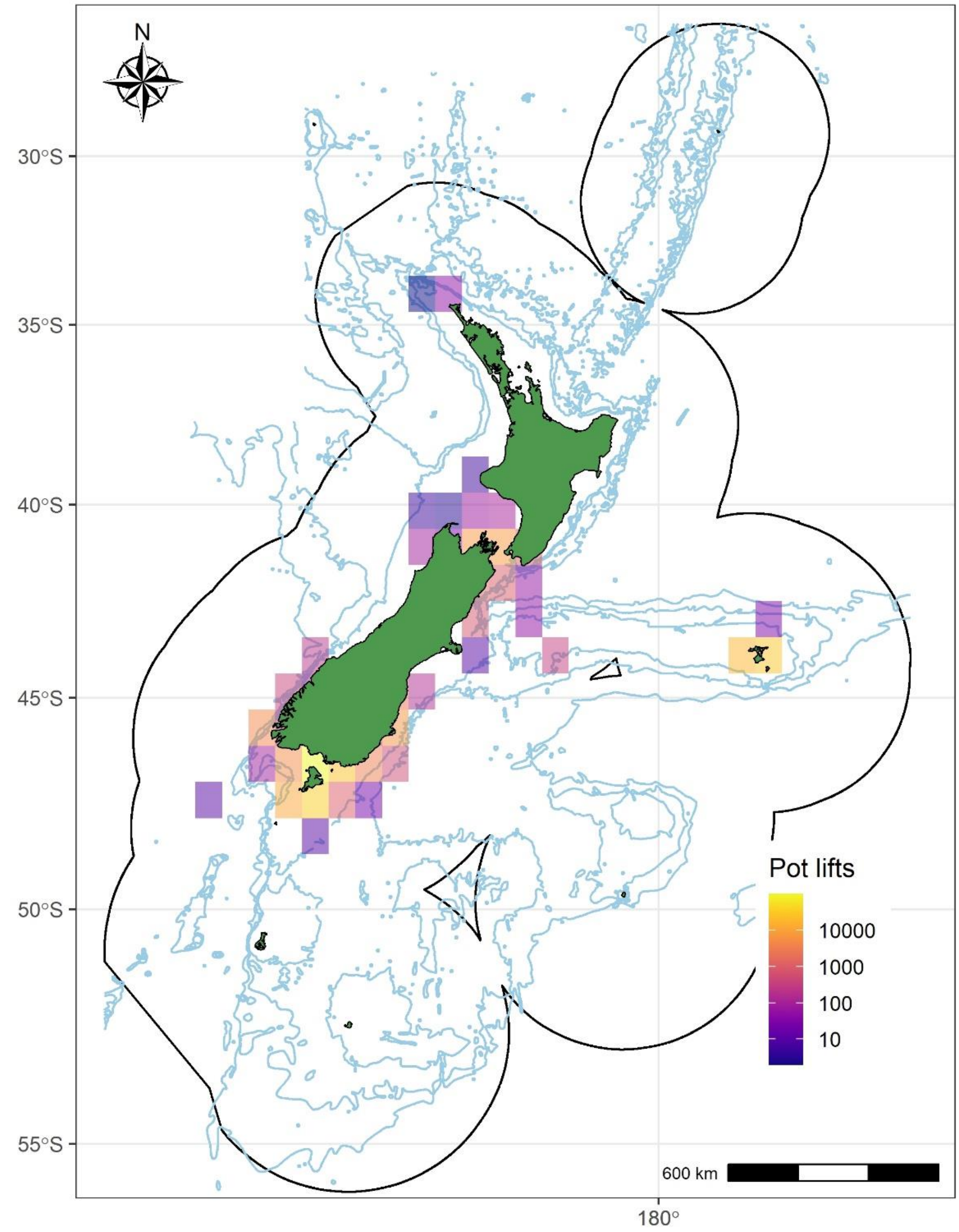

*Figure 12. Fisher-reported pot fishing effort (total number of pot lifts) targeting blue cod (*Parapercis colias*), 1 January 2019 – 30 September 2021. Pot lift density is shown in 1-degree squares.*

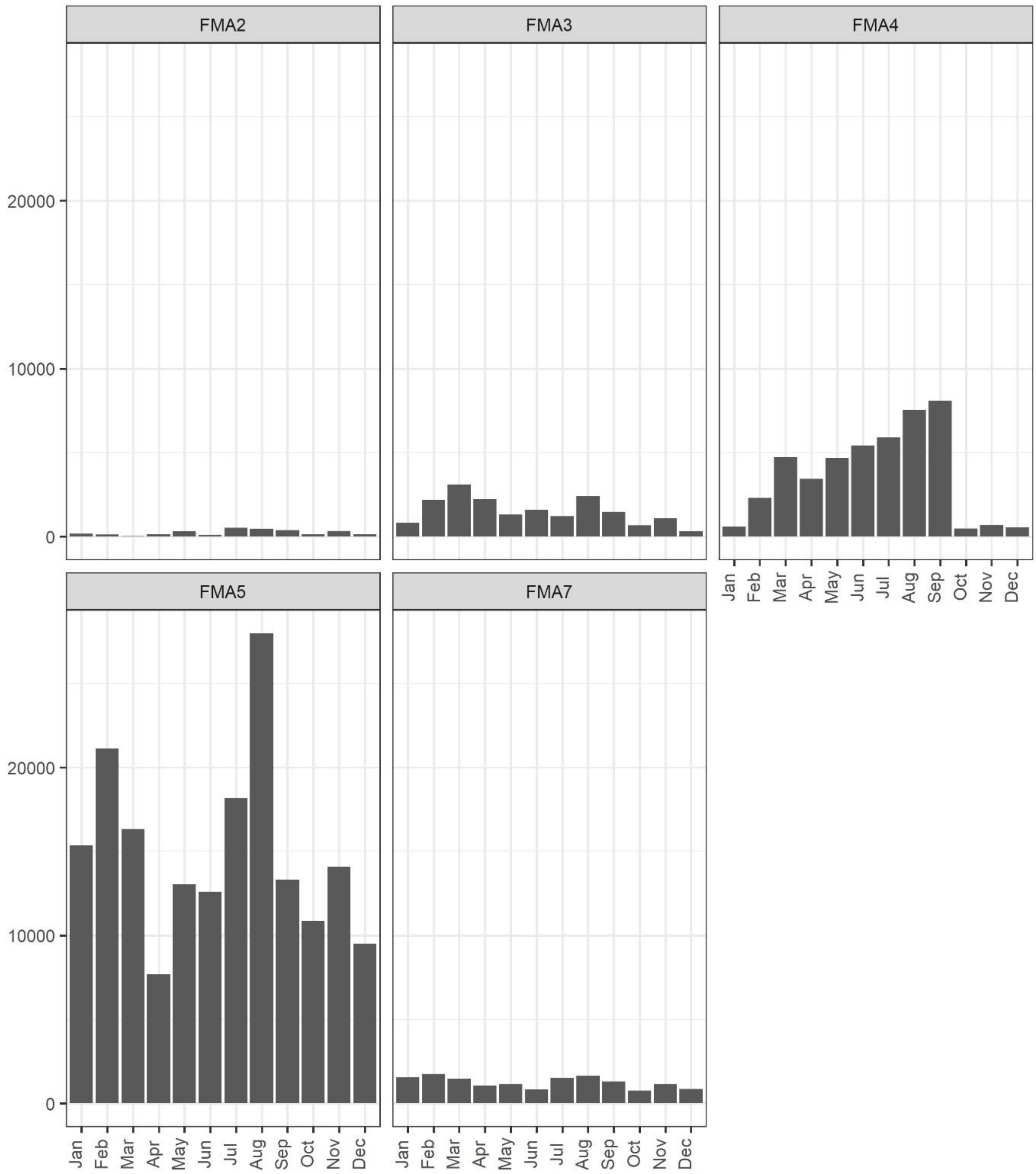

*Figure 13. Monthly fisher-reported pot fishing effort (total number of pot lifts) targeting blue cod (*Parapercis colias*), 1 January 2017 – 30 September 2021. Pot lifts are shown by New Zealand Fisheries Management Areas.*

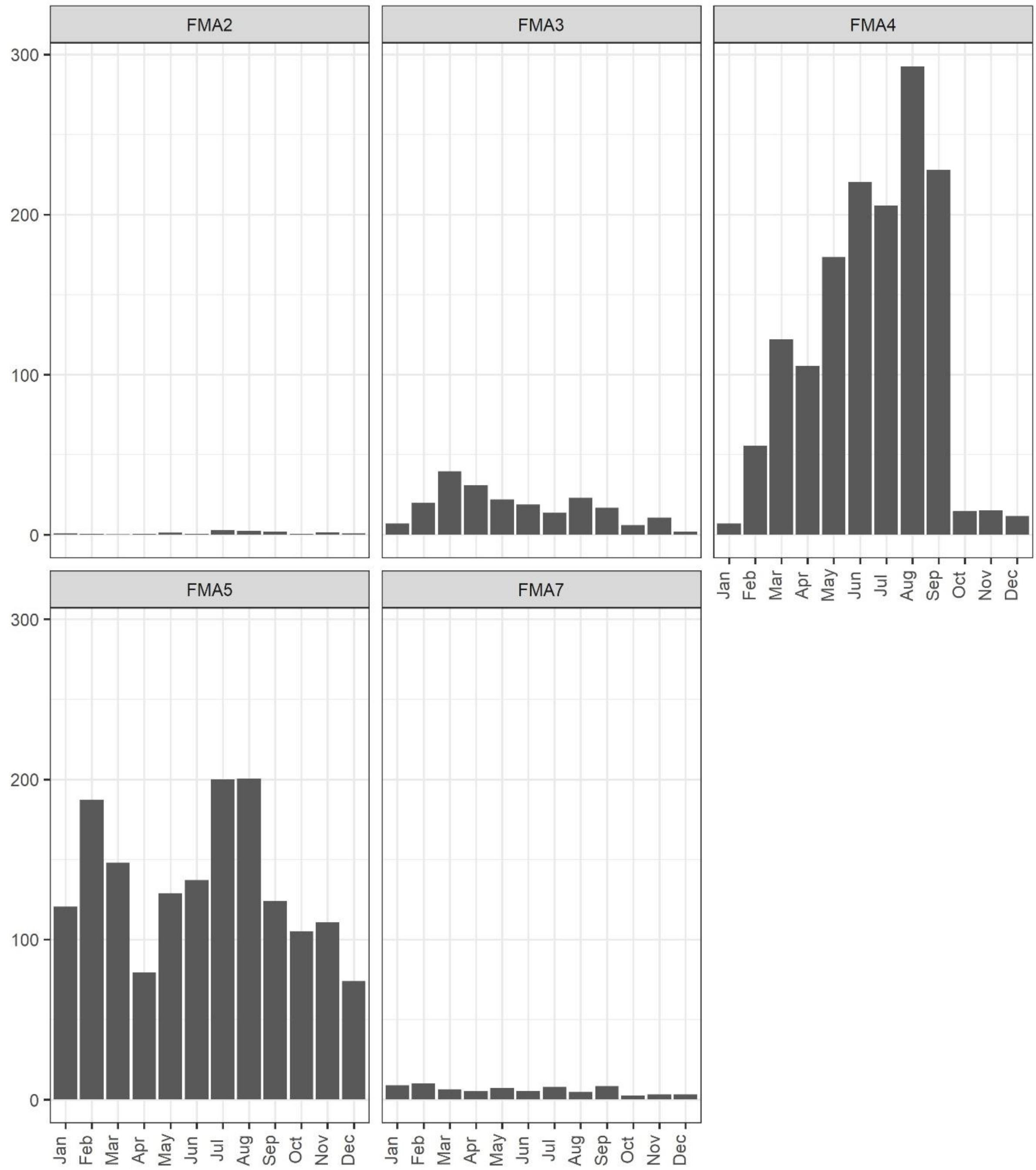

*Figure 14. Monthly fisher-reported pot fishing catch (t) of blue cod (*Parapercis colias*), 1 January 2017 – 30 September 2021, shown by New Zealand Fisheries Management Areas.*

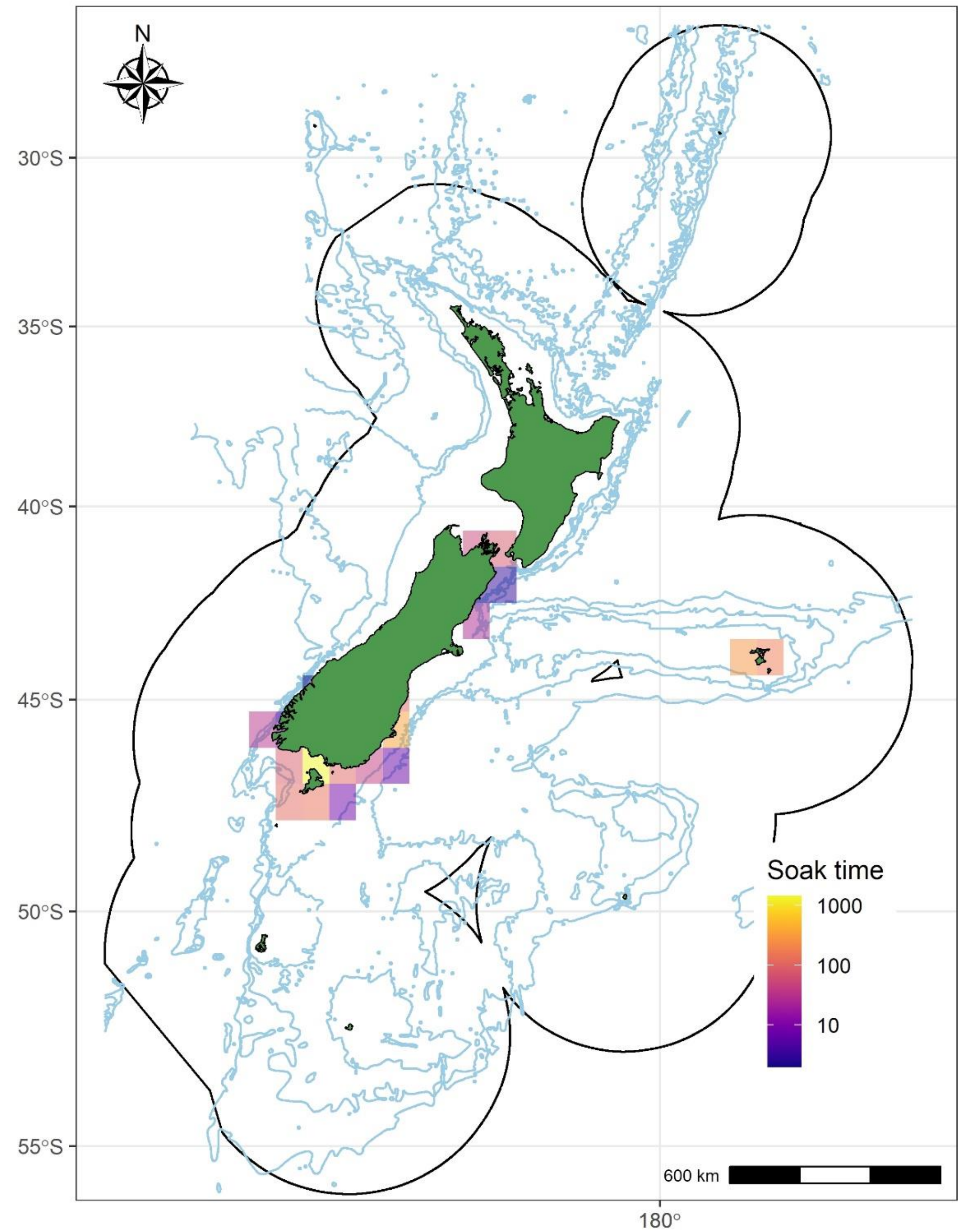

*Figure 15. Fisher-reported soak time (total number of hours) for pot fishing targeting blue cod (*Parapercis colias*), 1 January 2019 – 30 September 2021, by one-degree squares.*

3.1.5 Ling

Pot fishing effort targeting ling appears in catch effort data from 2017 onwards. Exploratory potting for ling commenced in Cook Strait and off the Wairarapa Coast, and operators then moved into an area south of the Chatham Rise. Effort varies with the availability of Annual Catch Entitlement (ACE) and fishers prefer to target ling spawning areas. Among operators, interest in ling potting is reported to be increasing, such that pot fishing effort targeting ling is expected to grow in the near future. Gear is set as a line of connected pots with one surface rope and buoy. The approach to setting pots for ling is referred to as “trot line potting” by some operators (J. Cleal, pers. comm.).

Depths of up to several hundred metres are fished. Beyond Cook Strait, the Wairarapa Coast and the Chatham Rise, a small amount of reported pot fishing effort targeting ling has occurred elsewhere, e.g. off the West Coast of central New Zealand and Otago Peninsula (Figure 16). Commensurate with the location of most pot fishing effort targeting ling, catch was concentrated in FMAs 3 and 4. Effort and catch peaked in mid- to late winter in FMA 3 and autumn to mid-winter FMA 4 (Figure 17, Figure 18). Total pot soak times showed some variation, being longest off the east coast of the South Island and shortest off the west coast of the North Island (Figure 19).

3.1.6 Hagfish

Most pot fishing effort targeting hagfish is reported from the east coast of the North Island and off the west coast of the South Island (FMAs 2 and 7). A localised area of effort also appears on the Chatham Rise (Figure 20). Effort is concentrated from late winter to early summer in FMA 2, compared to the summer months of January and February in FMA 7 (Figure 21). The information available showed that total soak times were notably shorter for hagfish compared to other species targeted using this method. However, soak time information was only available for a subset of fishing effort in the dataset and appears unlikely to be representative of this fishery (Figure 22).

3.1.7 Paddle crab

Paddle crab pot fishing effort is discontinuous around the coast of the main islands of New Zealand. Since 2017, effort has been highest around Otago Peninsula and Cook Strait (Figure 23, Figure 24). Fishing effort peaked in the summer months (Figure 24). Total soak times were longest in these same areas, based on the available information (Figure 25). However, as for hagfish, soak time information was only available for a subset of fishing effort and the information available may not be representative.

REDACTED

*Figure 16. Fisher-reported pot fishing effort (total number of pot lifts) targeting ling (*Genypterus blacodes*), 1 January 2019 – 30 September 2021. Pot lift density is shown in 1-degree squares.*

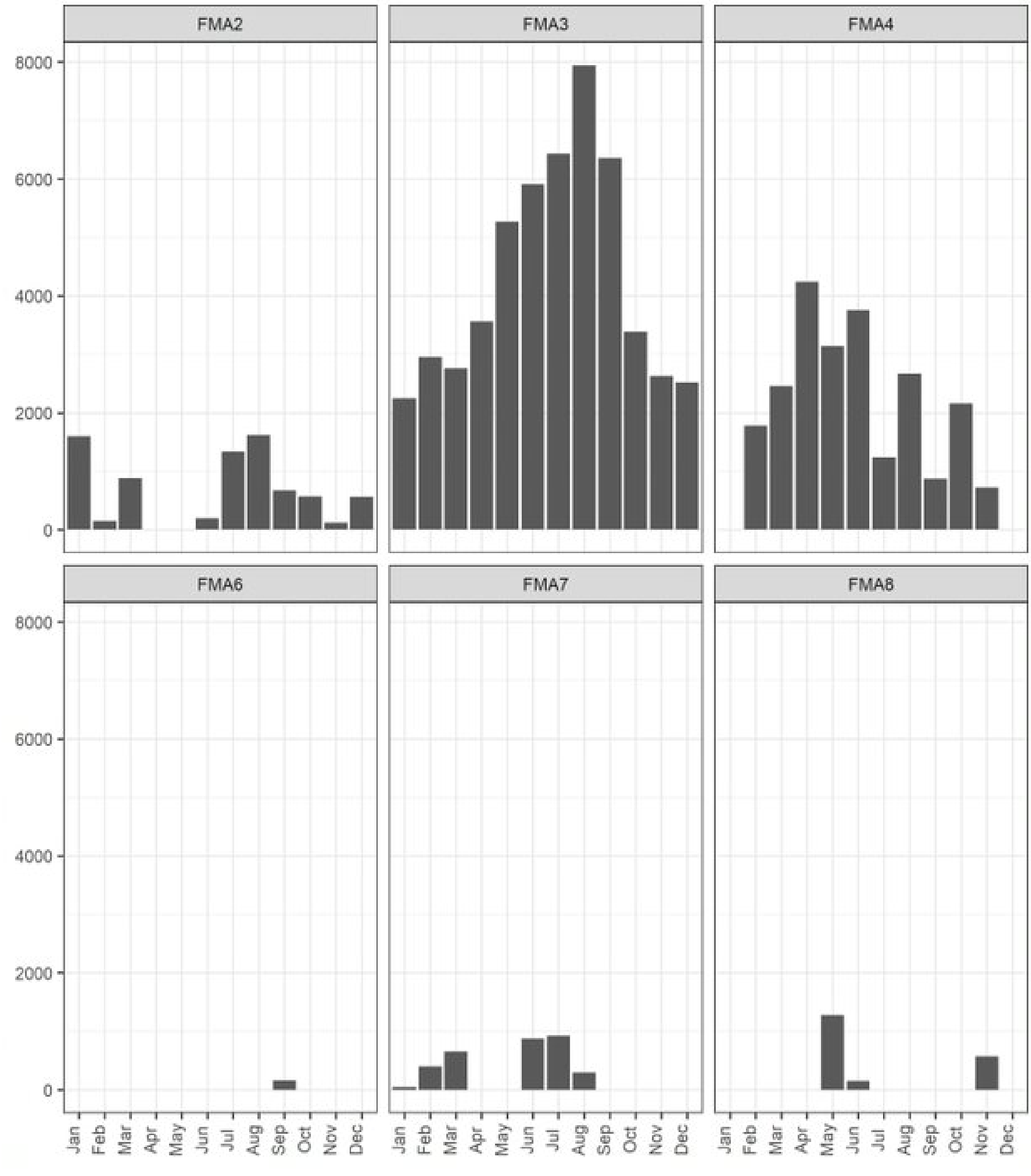

*Figure 17. Monthly fisher-reported pot fishing effort (total number of pot lifts) targeting ling (*Genypterus blacodes*), 1 January 2017 – 30 September 2021. Pot lifts are shown by New Zealand Fisheries Management Areas.*

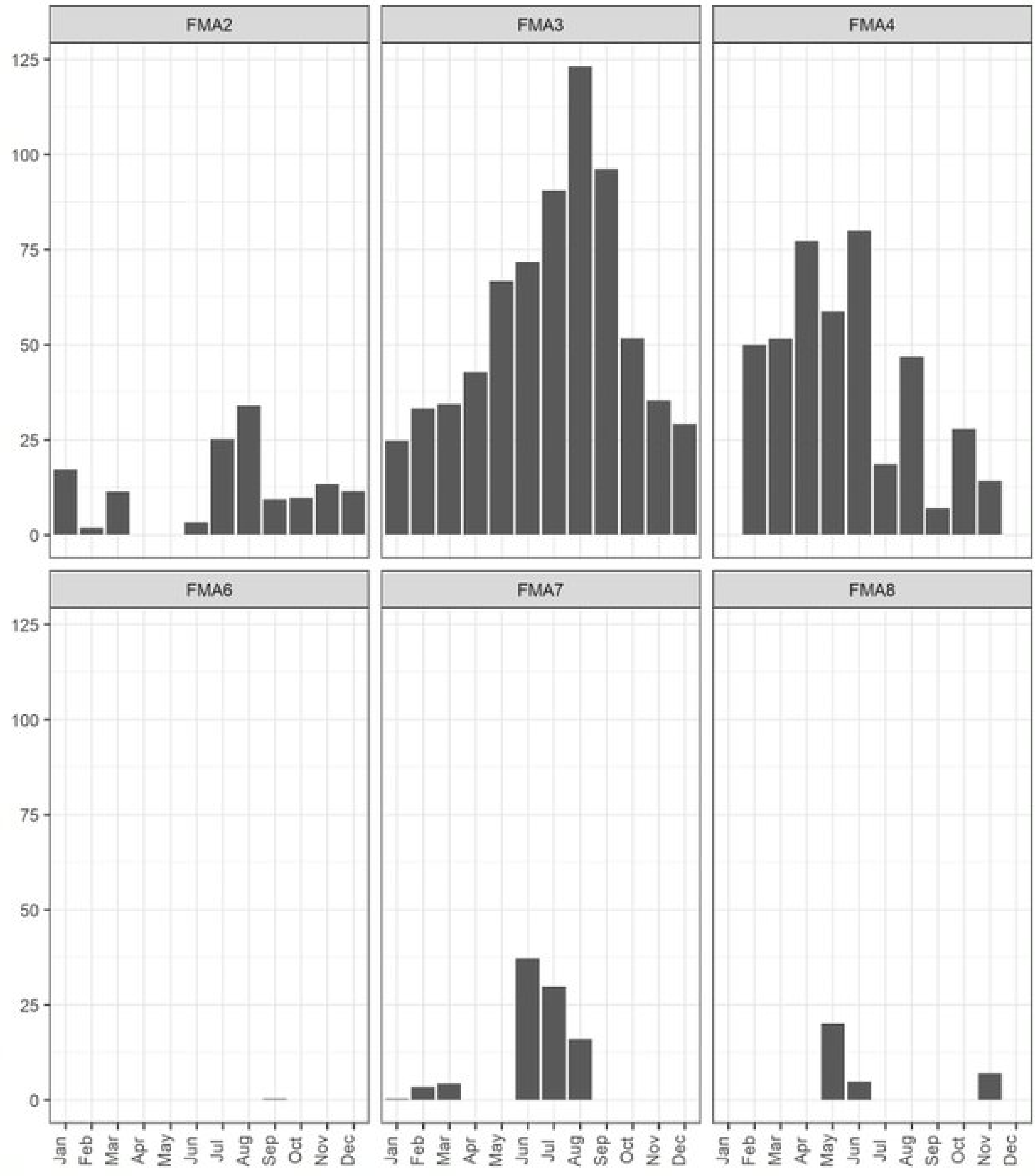

*Figure 18. Monthly fisher-reported pot fishing catch (t) of ling (*Genypterus blacodes*), 1 January 2017 – 30 September 2021, shown by New Zealand Fisheries Management Areas.*

REDACTED

*Figure 19. Fisher-reported soak time (total number of hours) for pot fishing targeting ling (*Genypterus blacodes*), 1 January 2019 – 30 September 2021, by one-degree squares.*

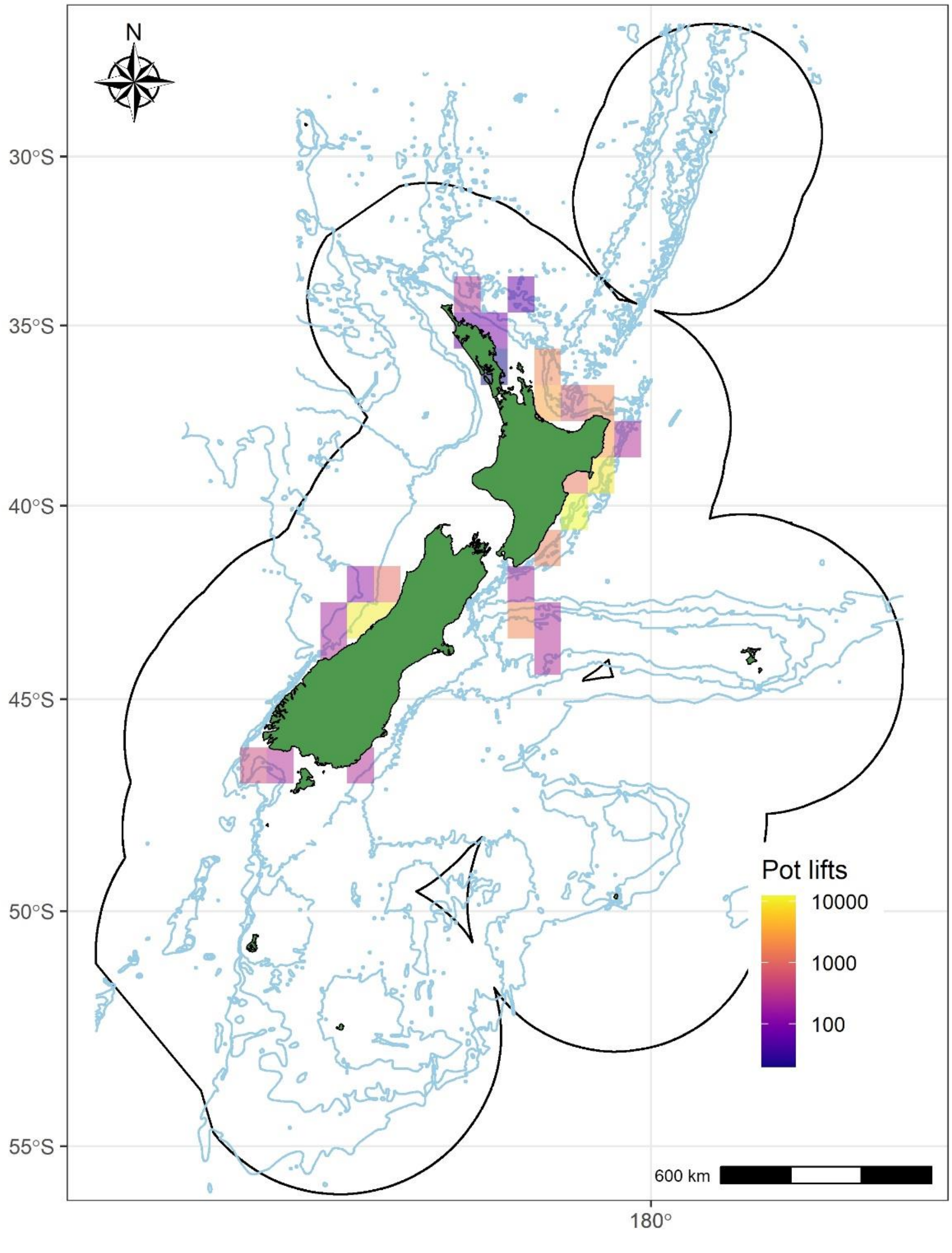

*Figure 20. Fisher-reported pot fishing effort targeting hagfish (*Eptatretus cirrhatus*), 1 January 2019 – 30 September 2021. Pot lift density is shown in 1-degree squares.*

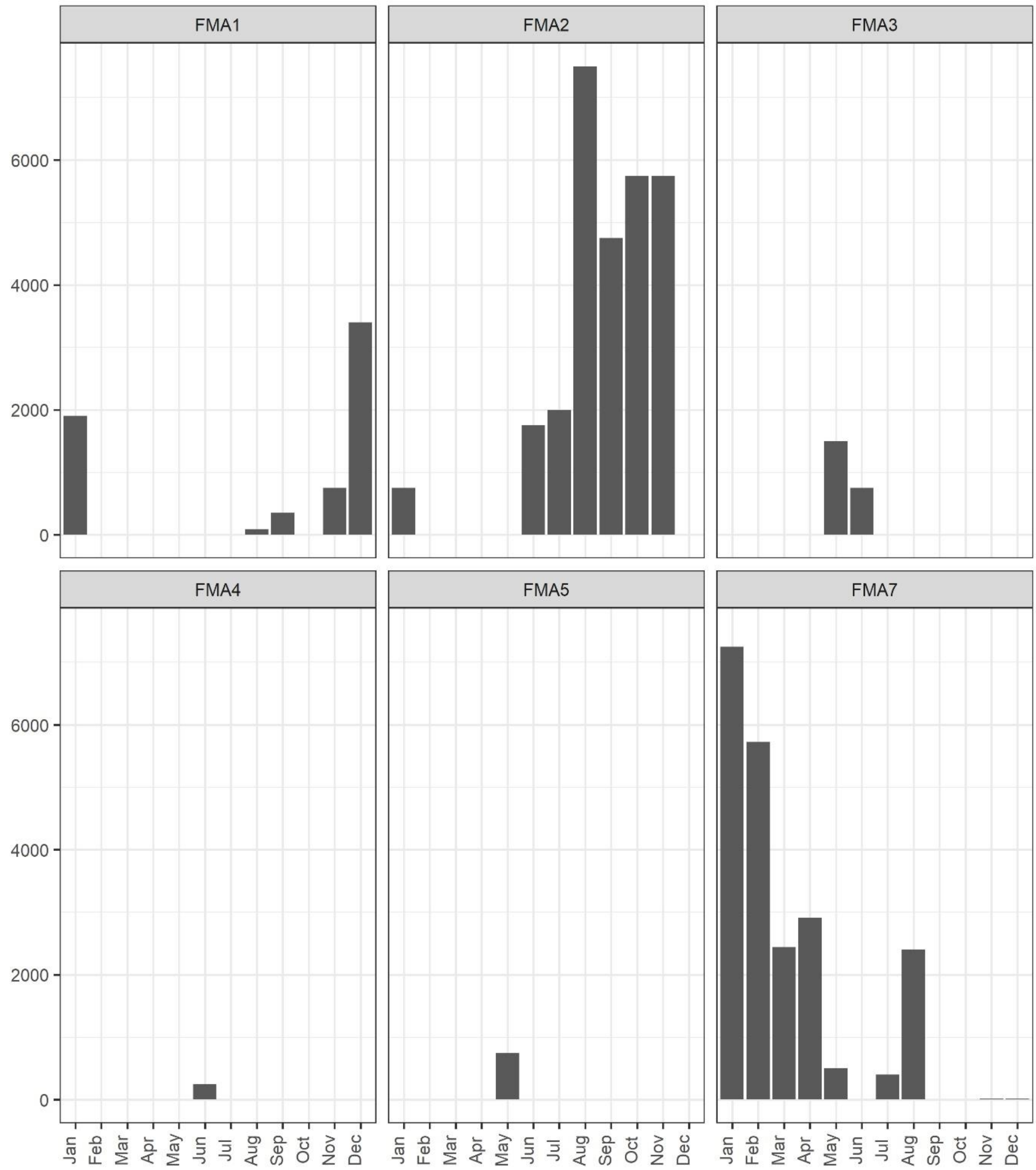

*Figure 21. Monthly fisher-reported pot fishing effort (total number of pot lifts) targeting hagfish (*Eptatretus cirrhatus*), 1 January 2017 – 30 September 2021. Pot lifts are shown by New Zealand Fisheries Management Areas.*

REDACTED

*Figure 22. Fisher-reported soak time (total number of hours) for pot fishing targeting hagfish (*Eptatretus cirrhatus*), 1 January 2019 – 30 September 2021, by one-degree squares.*

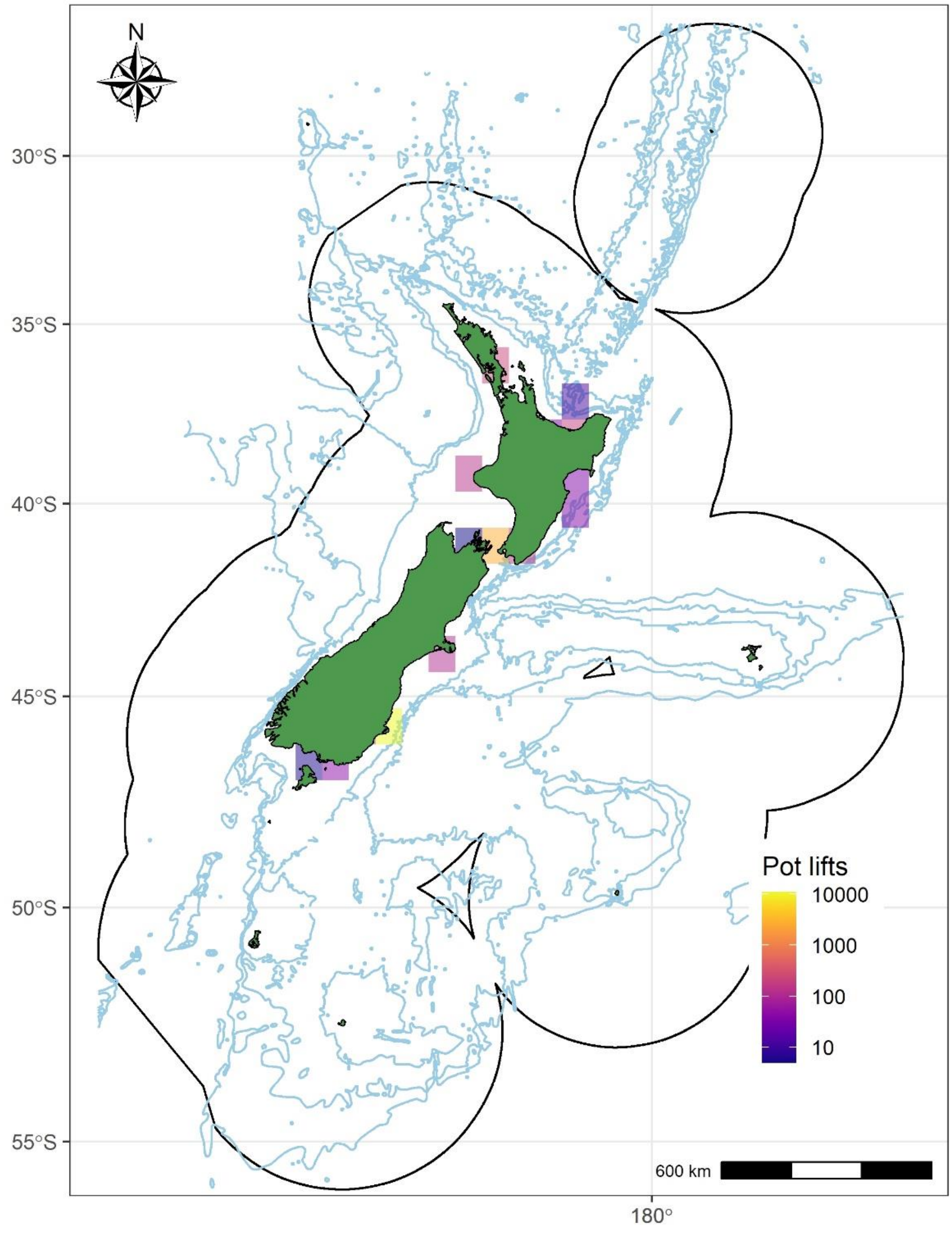

*Figure 23. Fisher-reported pot fishing effort targeting paddle crab (*Ovalipes catharus*), 1 January 2019 – 30 September 2021. Pot lift density is shown in 1-degree squares.*

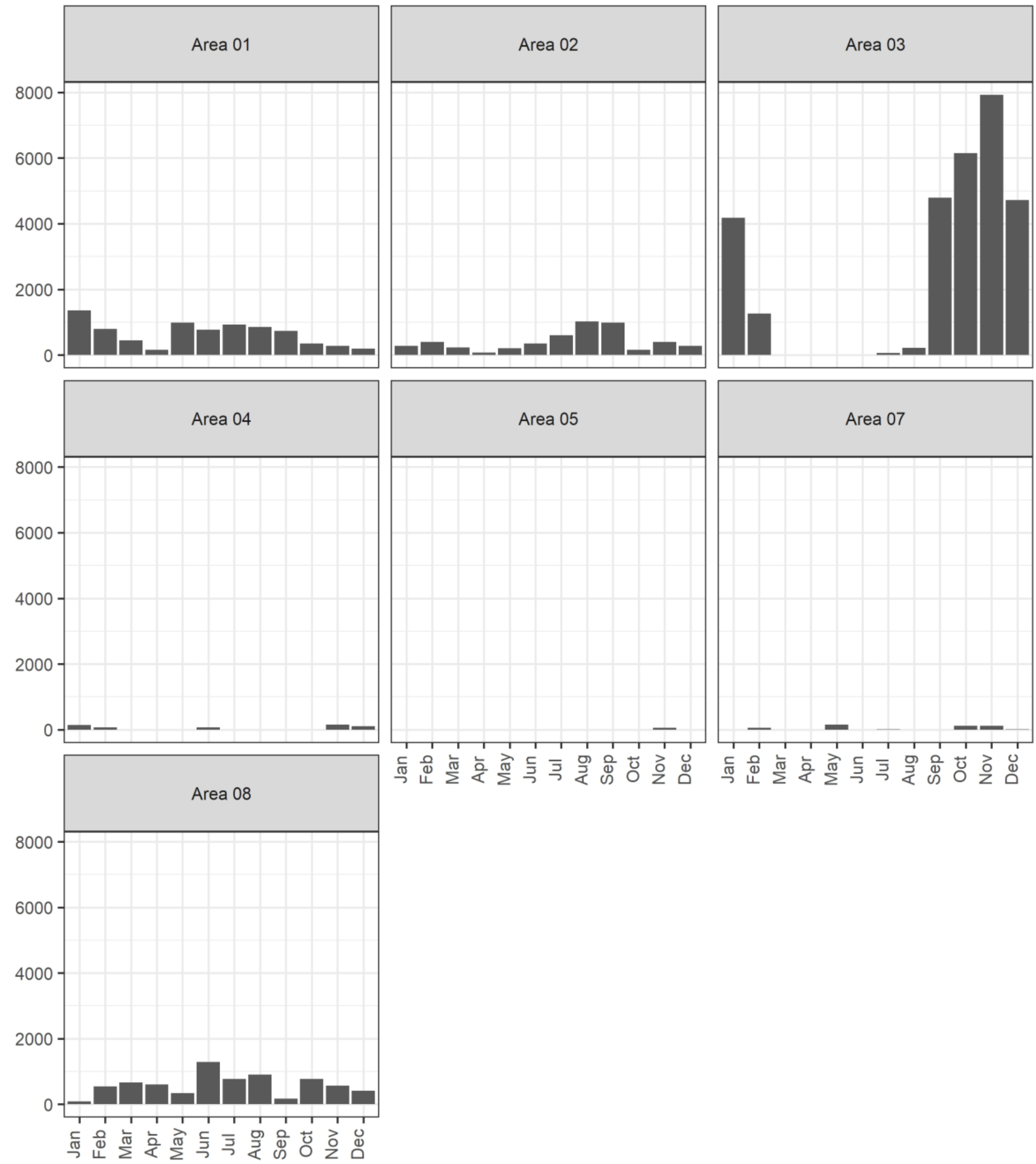

*Figure 24. Monthly fisher-reported pot fishing effort (total number of pot lifts) targeting paddle crab (*Ovalipes catharus*), 1 January 2017 – 30 September 2021, by region of New Zealand. Regions approximate New Zealand Fisheries Management Areas (Appendix 3).*

REDACTED

*Figure 25. Fisher-reported soak time (total number of hours) for pot fishing targeting paddle crab (*Ovalipes catharus*), 1 January 2019 – 30 September 2021, by one-degree squares.*

3.1.8 Rope hours

The time series of soak time information is still short. However, we present the following figures to demonstrate the method and illustrate how this metric could be used to explore entanglement risk. Based on currently available data, rope hours varied through the months of the year and were consistently high around the Chatham Islands through the year except April. Rope hours tended to be lower in most other areas in May and June, while spread more widely in those months. In general, rope hours increase again into July and August (Figure 27, Figure 28).

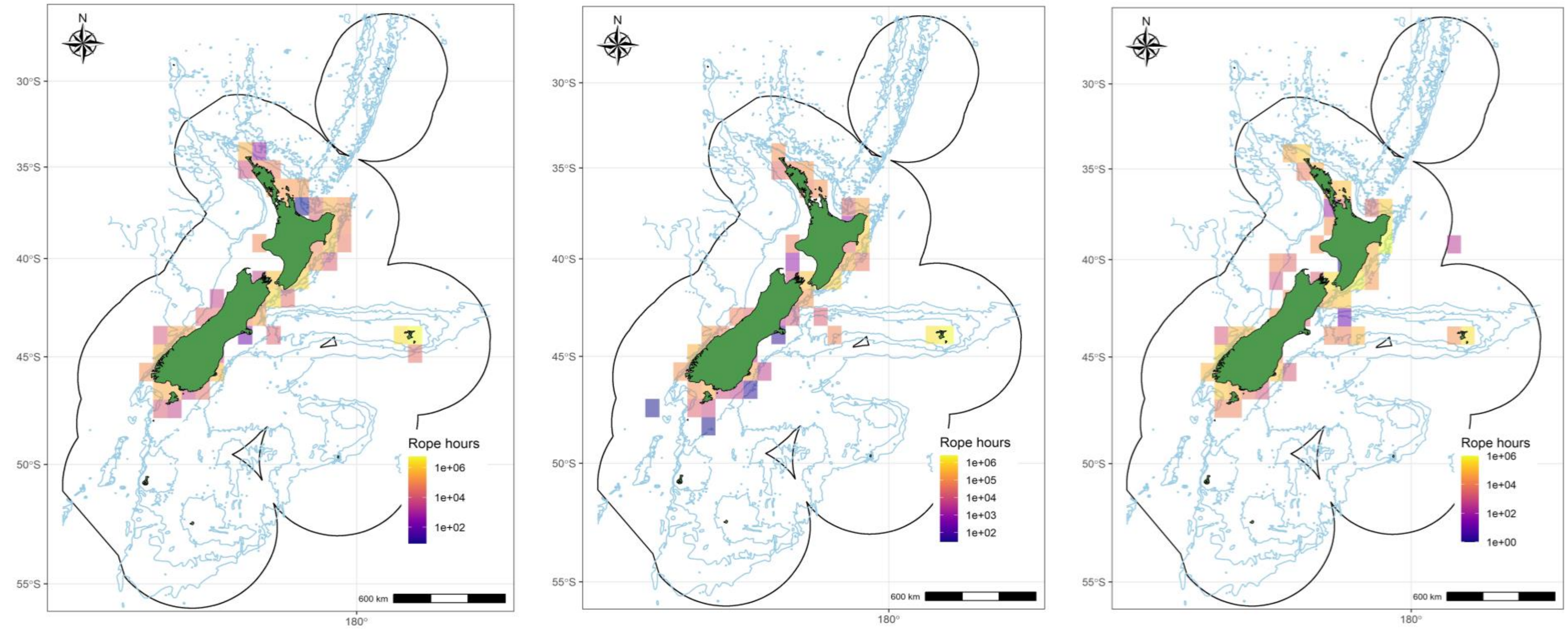

Figure 26. Rope hours (fisher-reported soak time multiplied by number of pot lifts) associated with pot fishing in New Zealand waters shown in one degree squares, 1 January 2019 – 30 September 2021. Panels from L – R: January, February, March.

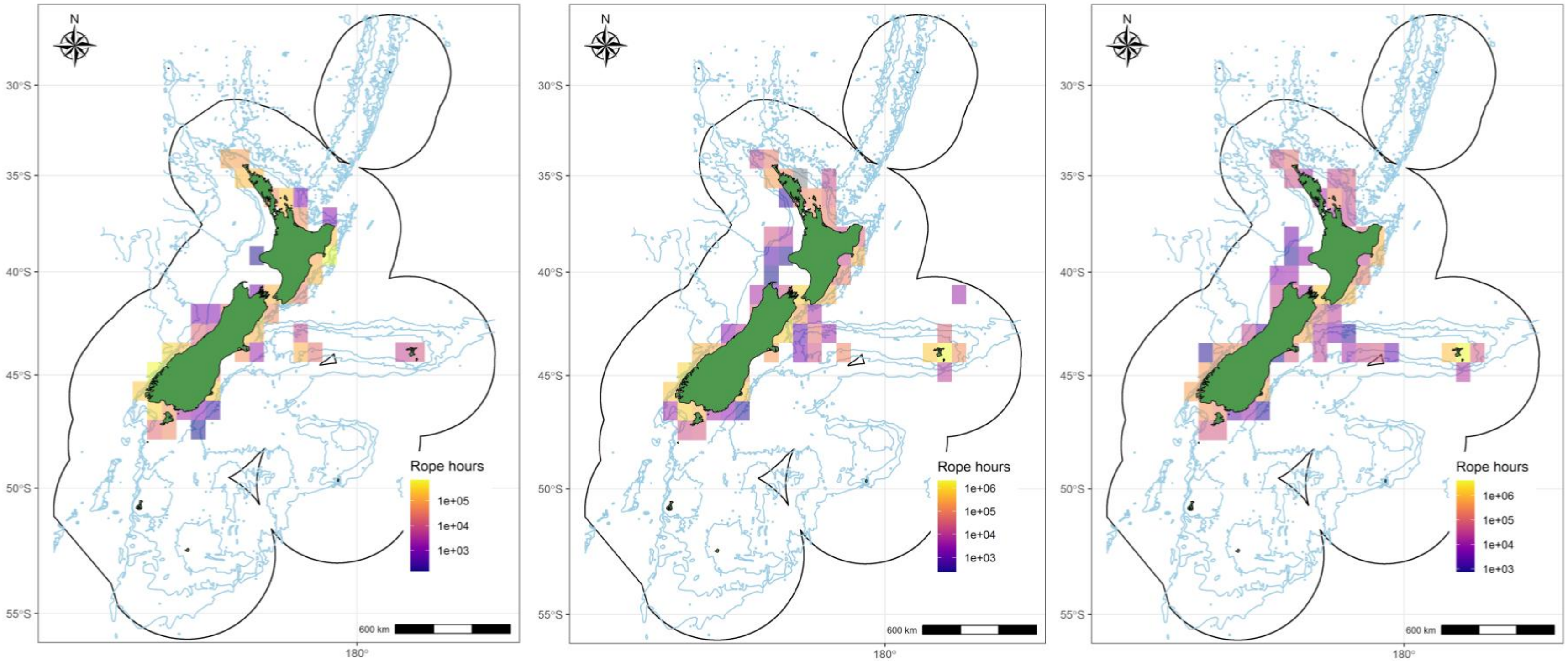

Figure 27. Rope hours (fisher-reported soak time multiplied by number of pot lifts) associated with pot fishing in New Zealand waters shown in one degree squares, 1 January 2019 – 30 September 2021. Panels from L – R: April, May, June.

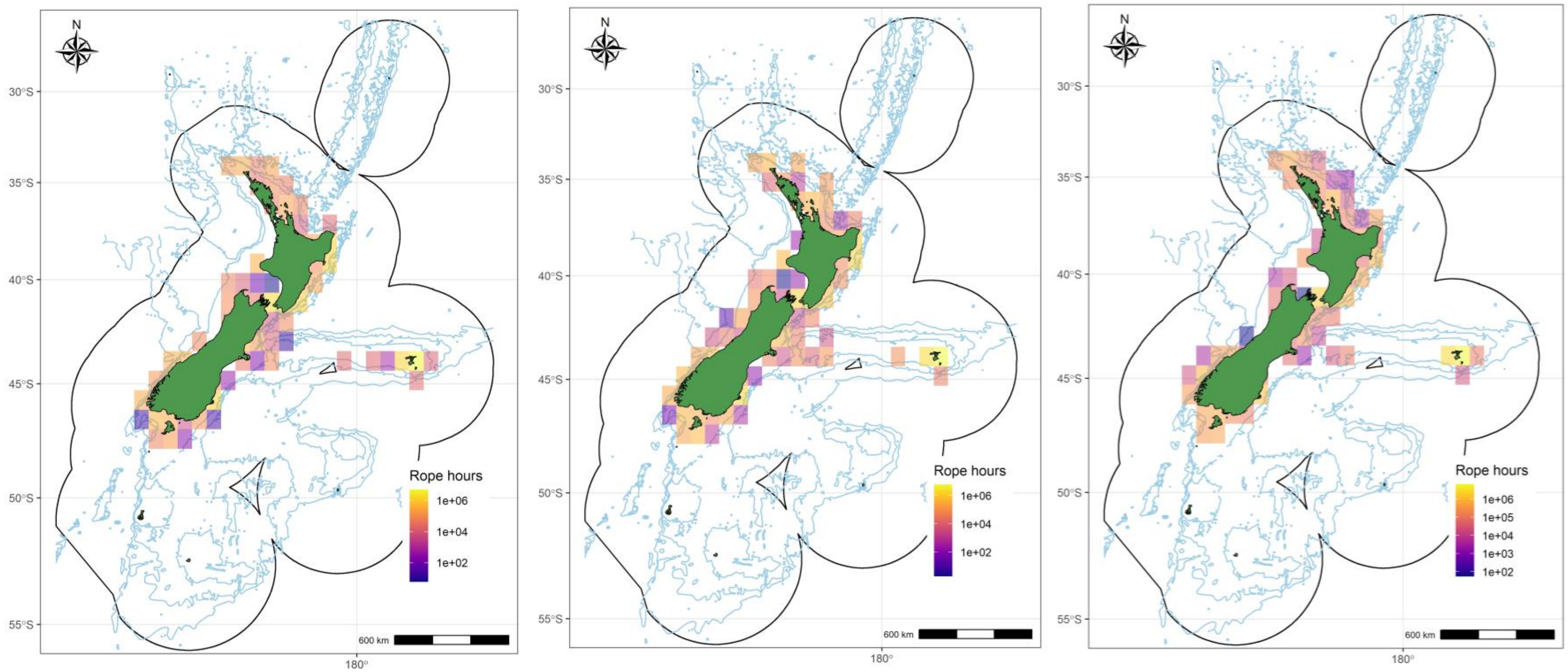

Figure 28. Rope hours (fisher-reported soak time multiplied by number of pot lifts) associated with pot fishing in New Zealand waters shown in one degree squares, 1 January 2019 – 30 September 2021. Panels from L – R: July, August, September.

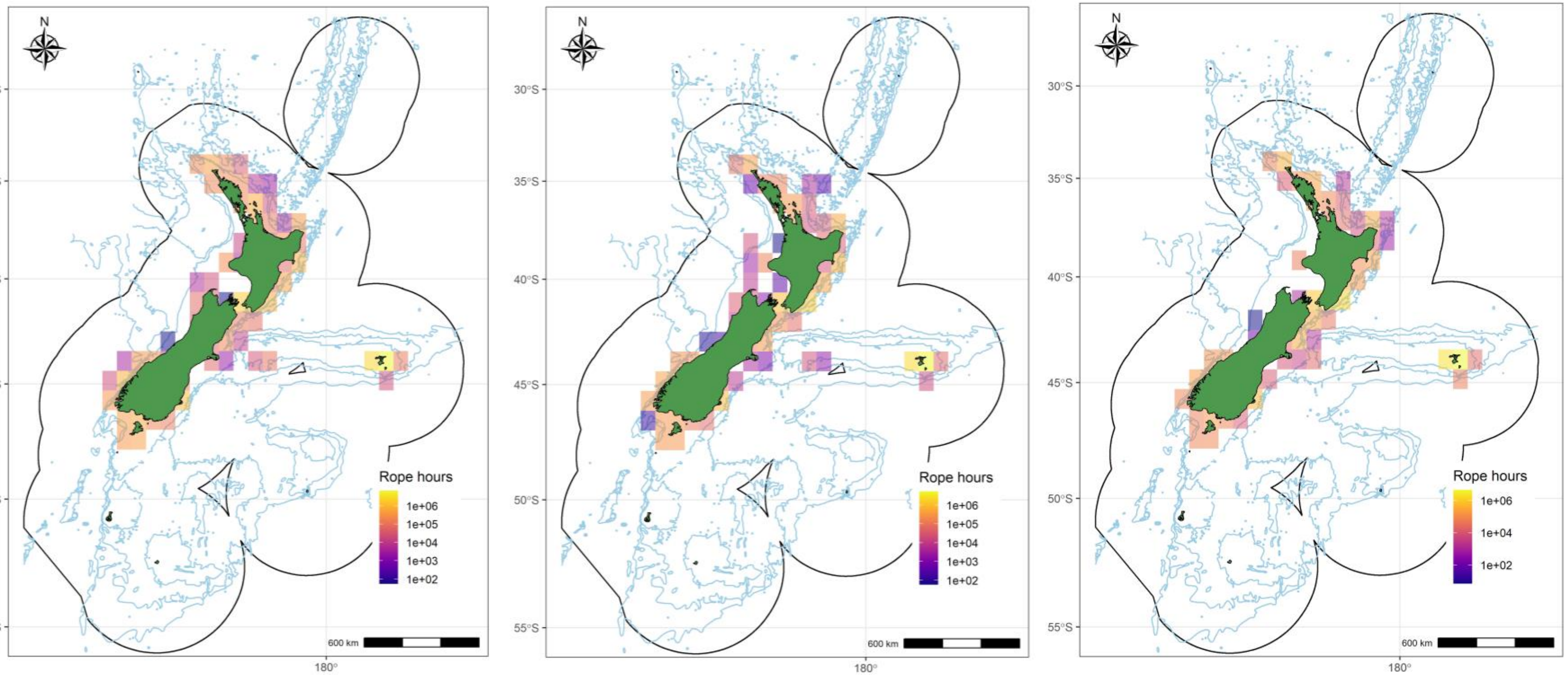

Figure 29. Rope hours (fisher-reported soak time multiplied by number of pot lifts) associated with pot fishing in New Zealand waters shown in one degree squares, 1 January 2019 – 30 September 2021. Panels from L – R: October, November, December.

3.2 Cetacean entanglement events

Among all records available for this project (including records prior to 2017), entanglements were detected along the north-east coast of the North Island, Cook Strait and Marlborough, east coast of the South Island, and Fiordland and Stewart Island (Figure 30, Figure 31). Seventeen new entanglement records involving 18 entangled cetaceans have become available since the previous work reported by Laverick et al. (2017). Entanglements occurring since 2017 were reported in locations from Northland to Stewart Island (Figure 32, Figure 33; Appendix 1). No entanglements have been reported from the Chatham Islands.

Most recorded entanglements over time have involved humpback whales (Figure 34; Appendix 1). Entanglements since 2017 have involved a Bryde's whale (*Balaenoptera edeni*), pygmy right whale (*Caperea marginata*), southern right whales, humpback whales, unidentified species of *Balaenoptera*, orca, and Hector's dolphin (*Cephalorhynchus hectori*). Consistent with reports prior to 2017, the single taxa most often identified in entanglement records since 2017 is humpback whales (44% of 18 entangled animals). There were two entanglement events reported that involved each of the following taxa: orca, southern right whale (three animals entangled in two events), and *Balaenoptera* spp. (Appendix 1).

Entanglements have occurred in every month of the year since recordkeeping began. Over time, most entanglements have been reported in June, with almost all of these involving humpback whales. Orca entanglements have occurred in the spring and summer months, while events involving other species have occurred occasionally throughout the year. A considerable number of entanglement events involving humpback whales and orcas which did not contain specific date information (Figure 35). Since 2017, humpback entanglements have been reported from most months March through October, while orca entanglements were detected in September and December. Other whale reports were focused in the summer months (November, and January – March) (Figure 36).

The fishing gear type most recently described in entanglement reports is 'cray' (Figure 37). Some reports include more detailed gear descriptions including rope type and diameter, or numbers legible on buoys attached to entangled animals that identify individual commercial fishing vessels. Other records state that ropes, ropes and floats, net, and buoys were associated with the entangled animal, while a more specific identification was not included. Records did not routinely distinguish commercial or recreational fishing gear. Entanglement records involving 'cray' fishing gear are documented from all months except April, noting that the months in which some entanglements occurred are unknown (Figure 37). Among entanglement records available since 2017, 'cray' fishing gear continued to be most frequently identified (76%), with four reports including more general gear descriptions not linked to a target species/fishery (e.g. rope, floats, buoys; Figure 38).

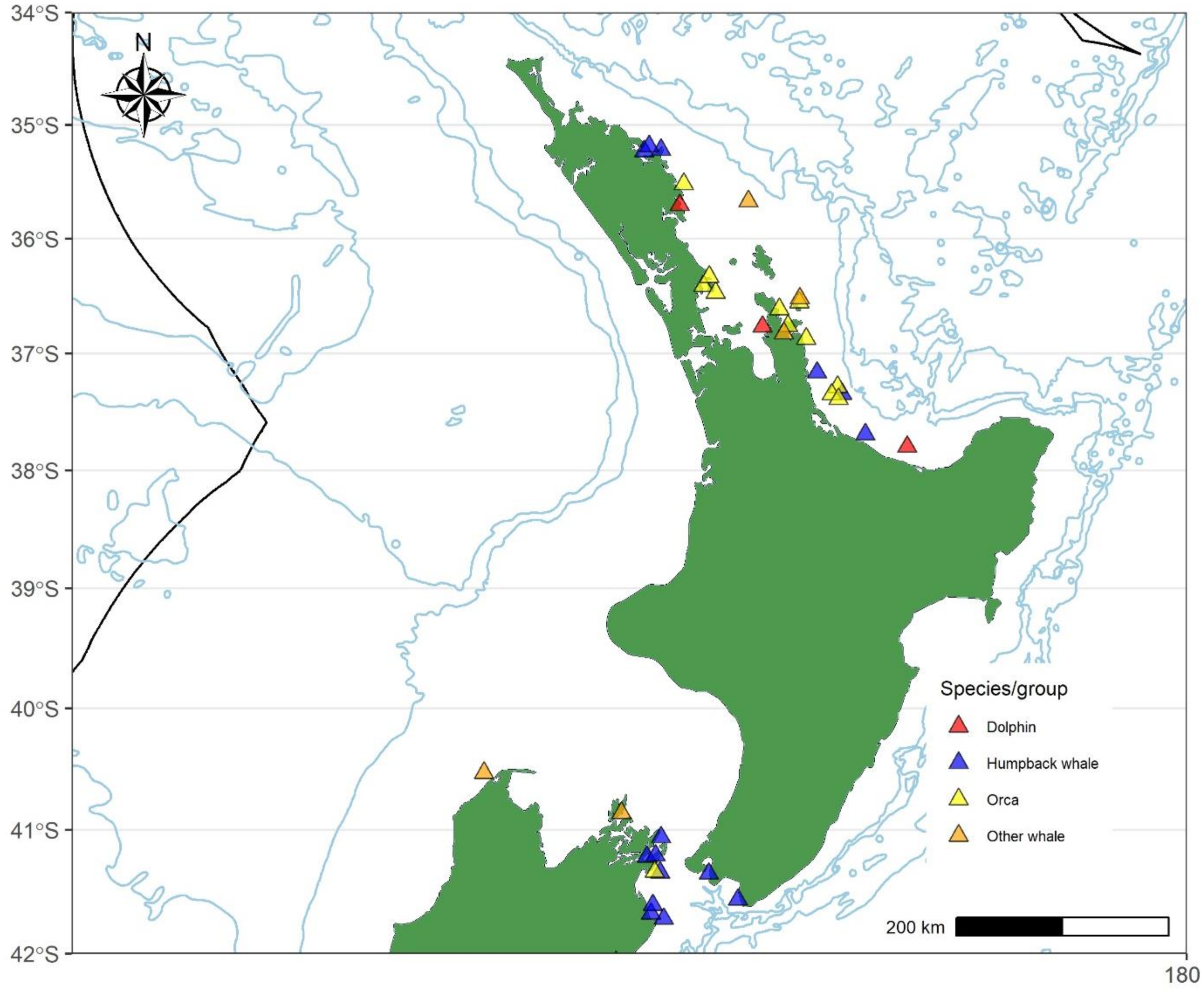

Figure 30. Cetacean entanglements recorded from around the North Island and top of the South Island of New Zealand, 2 July 1980 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

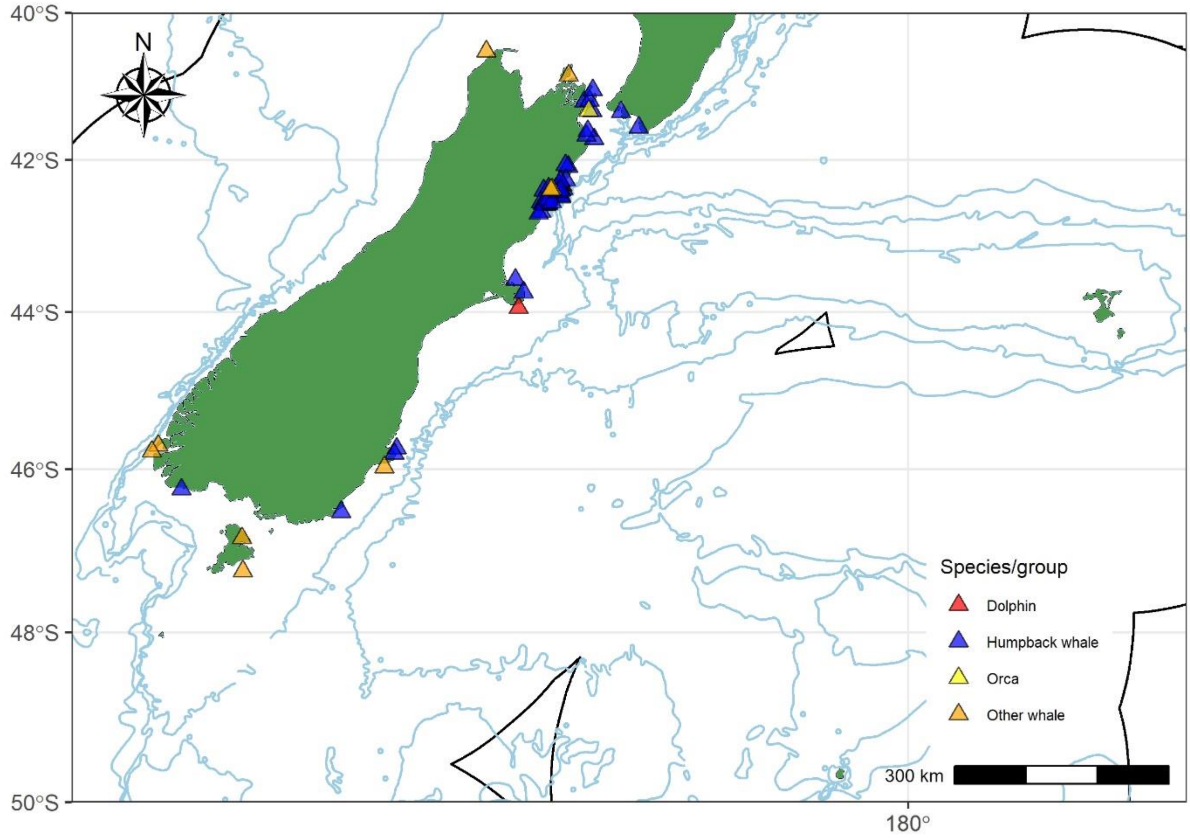

Figure 31. Cetacean entanglements recorded from southern New Zealand, 2 July 1980 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

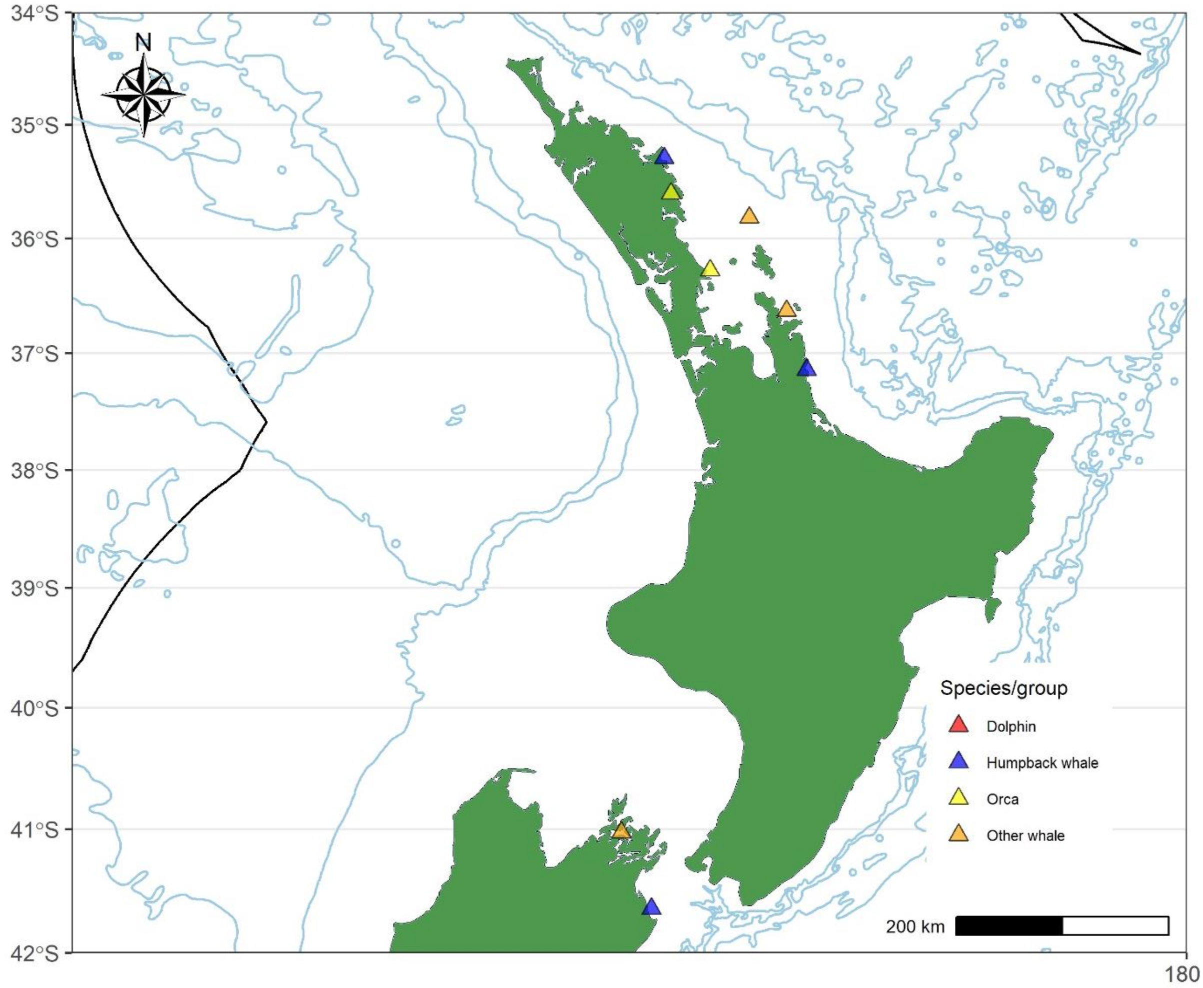

Figure 32. Cetacean entanglements recorded from around the North Island and top of the South Island of New Zealand, 1 January 2017 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

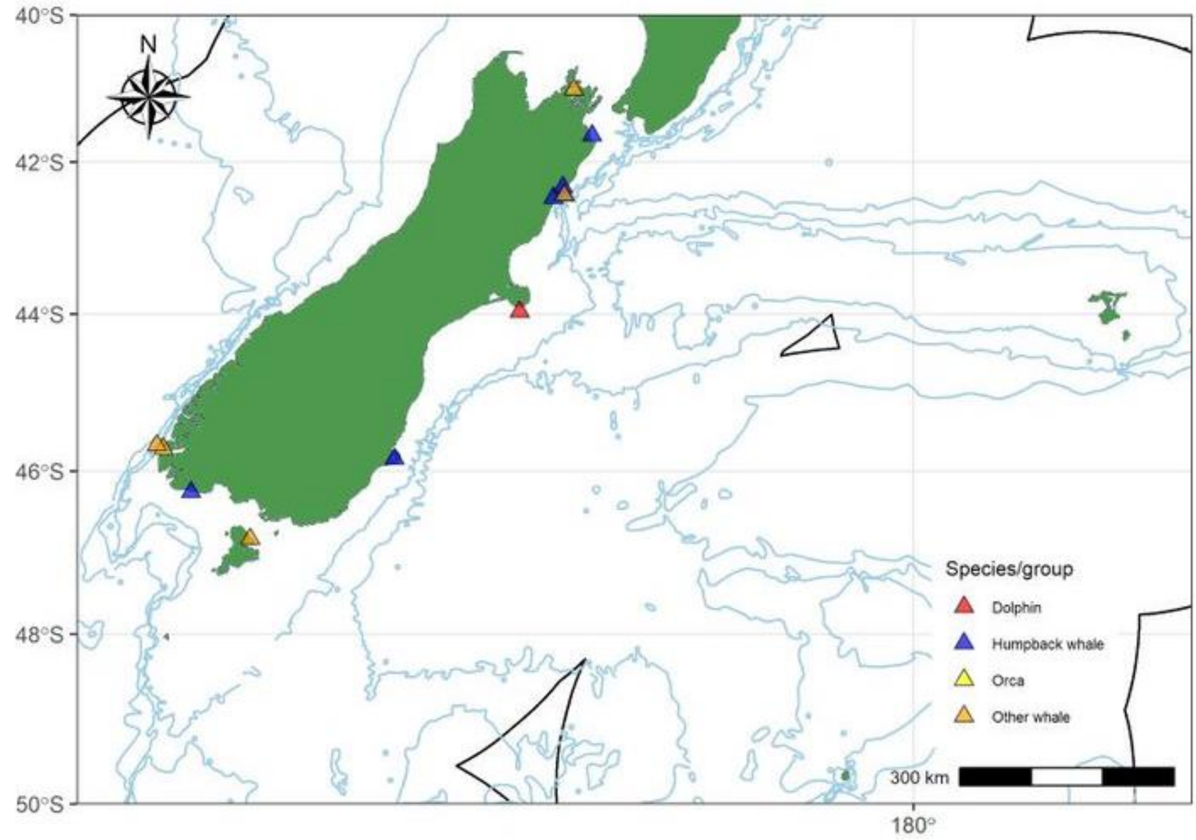

Figure 33. Cetacean entanglements recorded from southern New Zealand, 1 January 2017 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

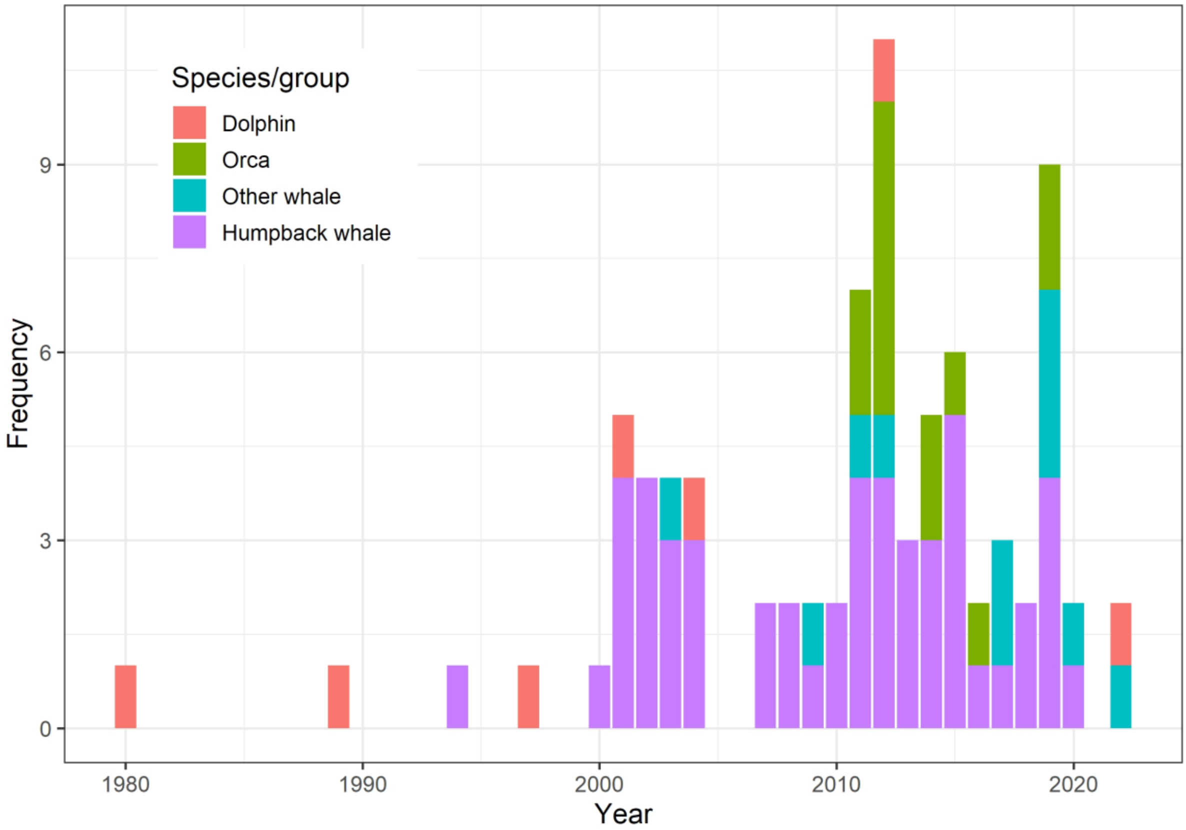

Figure 34. Cetacean entanglements recorded in New Zealand by year, from 2 July 1980 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

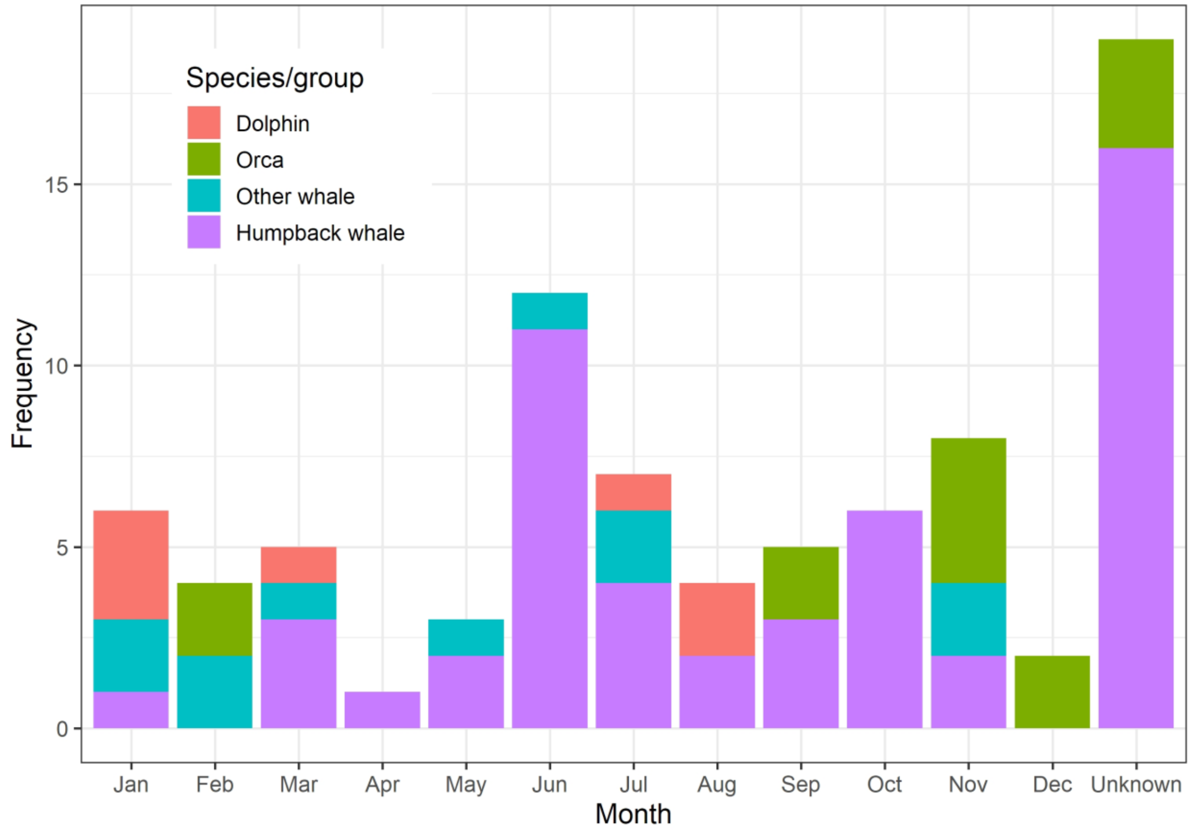

Figure 35. Number of cetacean entanglements recorded monthly in New Zealand, 2 July 1980 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

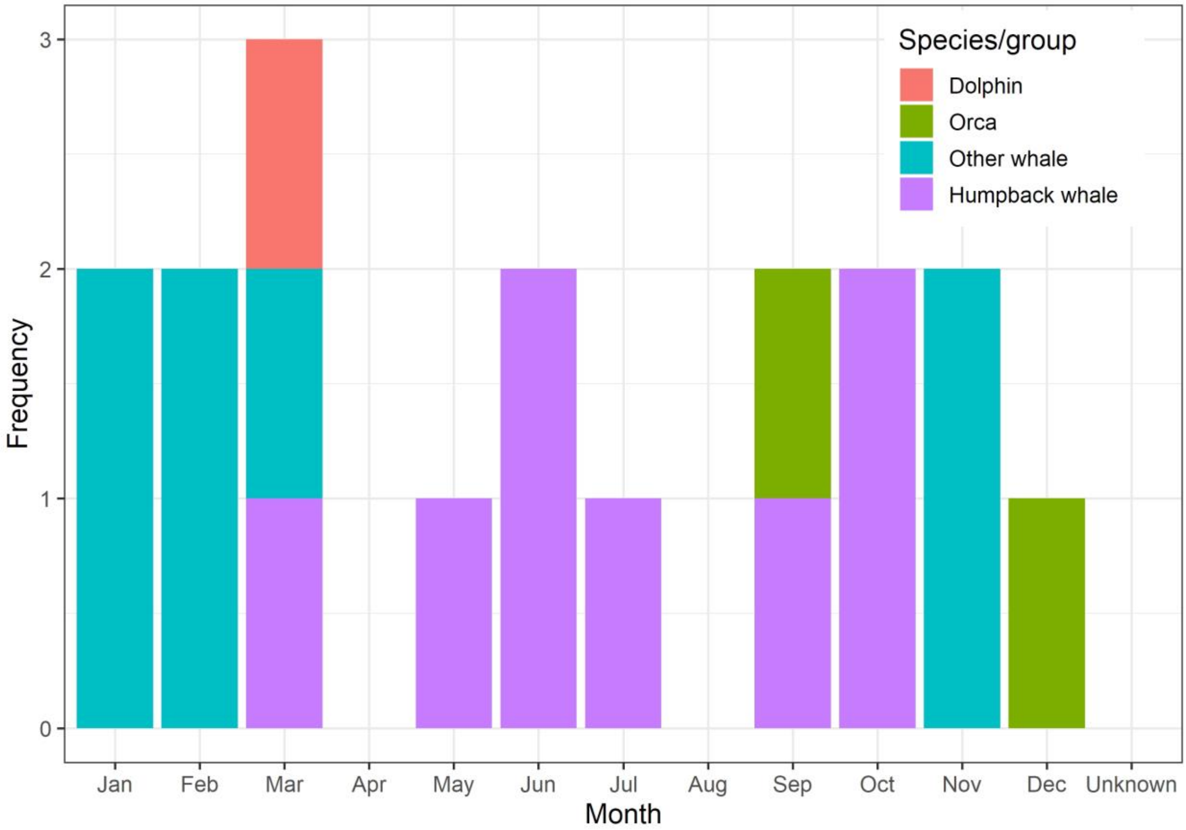

Figure 36. Number of cetacean entanglements recorded monthly in New Zealand, 1 January 2017 – 14 March 2022. Taxa involved in each entanglement event are listed in Appendix 1.

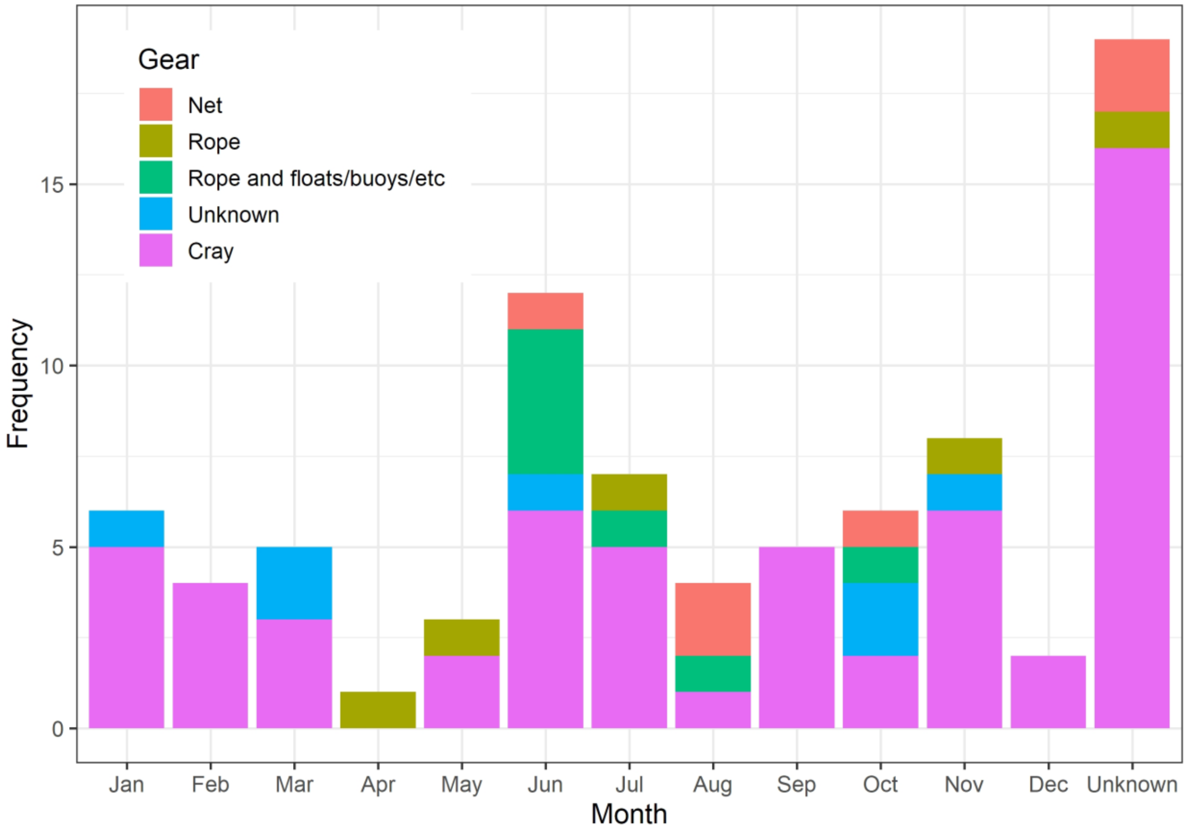

Figure 37. Number of cetacean entanglements recorded monthly in New Zealand, 2 July 1980 – 14 March 2022, categorised by fishing gear identified in entanglement reports.

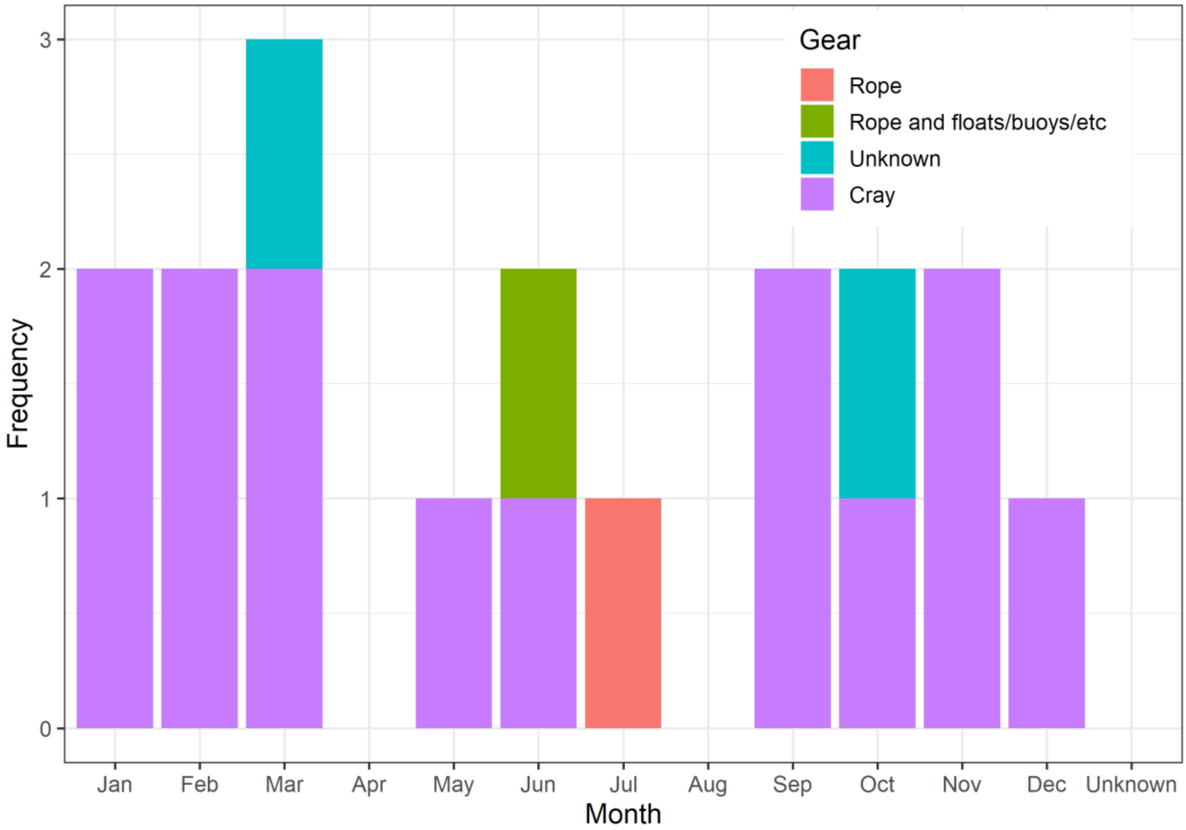

Figure 38. Number of cetacean entanglements recorded monthly in New Zealand, 1 January 2017 – 14 March 2022, categorised by fishing gear identified in entanglement reports.

3.3 Cetacean entanglement mitigation in pot fisheries

The literature search for recent information on whale entanglements identified 18 sources published between 2019-2021. Most sources (72%) dealt with recent increases in whale entanglements, namely involving the North Atlantic right whale (*Eubalaena glacialis*) in the Gulf of St. Lawrence, Canada (Cole et al. 2021; Lebon & Kelly 2019; Santora et al. 2020), humpback whales off the west coast of the USA (Feist et al. 2021; Moore 2019; Myers et al. 2019) and humpback whales in Australia (How et al. 2020a, 2020b, 2021; Tulloch et al. 2019). One report described a multi-stage approach to addressing increased entanglement risks considered likely to be commensurate with increasing humpback whale populations (Warren & Wooden 2020). Three recent reviews of mitigation measures were also considered (Hamilton & Baker 2019; Tremblay-Boyer & Berkenbusch 2020; Stevens 2021). Entanglement management mitigation options were varied, and included gear-associated options (gear modifications, acoustic deterrents and ropeless fishing), spatial and temporal closures, and whale ecology.

3.3.1 Identification and characterisation of the entanglement issue

A national assessment of cetacean bycatch and entanglement was conducted throughout Australian waters to assess the extent of the issue. Tulloch et al. (2019) highlighted the need for complete, consistent and accurate long-term data on cetacean entanglements/bycatch to ensure the issue can be properly addressed. There was an increase in reported entanglements since 2000, which was attributed to increased reporting, shifts in fishing effort and cetacean population recovery. Reporting also played a strong part in the spatial examination, highlighting hotspots on both the east and west coasts of Australia which coincided with high human population areas, high fishing effort and high density of migrating humpback whales as well as east coast shark control gear. Tulloch et al. (2019) concluded that standardised reporting of entanglements within and between jurisdictions as well as fishery effort data would greatly assist in prioritising locations, times and fisheries which require more effective mitigation measures to address entanglement.

3.3.2 Identifying mitigation options

Identification of management options to mitigate the entanglement of large whales with fishing gear typically involves workshops with fishers and regulators. A recent example was a workshop was convened in Western Australia between Government and the western rock lobster (*Panulirus cygnus*) industry in September 2019 (How et al. 2020b). This workshop involved presentations from research, management and compliance to set the scene for discussions later in the workshop. These discussions, led primarily by active fishers, identified a range of potential management arrangements which could be implemented to reduce whale entanglements or increase the options for disentanglement.

Fishers took the process a step further by recommending specific management measures which could be implemented if particular thresholds of entanglement levels were reached. These categories of options represented increasing levels of perceived operational complexity for fishers (Table 1). Low impact options were recommended for implementation as soon as possible, with moderate and high impact options to be considered should entanglements in rock lobster gear surpass 10 and 15 respectively in a year. Finally, a series of research areas was also suggested to enhance the knowledge surrounding humpback whales, how they become entangled and how fishing techniques could be adapted to reduce entanglement rates.

*Table 1. Categorised management options from a workshop between government and western rock lobster (*Panulirus cygnus*) fishers in Western Australia (How et al. 2020b).*

Low Impact Options
1. Extend the period when gear modifications are required to include the months of April and November
2. Apply a 7 day pull rule to the shallow water
3. Industry to undertake voluntary whale sightings surveys, using the whale sightings app
4. Explore options for some fishers to be trained and to deploy tracking buoys on entangled whales
5. Undertake a program to promote the positive measures undertaken by industry to mitigate interactions with whales
Moderate Impact Options
6. Reduce pot usage rates during May to November, and implement a sliding scale of pot usage reductions such that smaller operators are still viable.
7. Implement more drastic reduction in pot usage rates during the northern whale migration (i.e. May – July)
8. Make the use of lead core rope (spliced into rope) mandatory
High Impact Options
9. Implement a water depth-based fishing closure during the northern migration
10. Increase depth at which fishers are allowed to use 3 floats
11. Shorten the length of rope which can be used to 1.5 times the water depth
12. Adjust float rigs such that floats detach easily should a whale become entangled
13. Decrease pot usage rates and re-define them in terms of the number of vertical lines

In eastern Australia, options to address increasing entanglement risks commensurate with increasing humpback whale populations were explored by Warren & Wooden (2020). The focal fishery for this work was the New South Wales Ocean Line and Trap fishery. Target species are demersal fish and spanner crab (*Ranina ranina*). The work programme considered gear modifications such as negatively buoyant head ropes, galvanic time releases, and subsurface ropes. Evaluations of the performance and feasibility of each measure considered safety, practicality, implications for lost gear, and cost. Recommendations included additional proposals for gear trials, and a gear survey to inform the assessment of costs associated with any potential future adoption of modified gear (Warren & Wooden 2020).

3.3.3 Processes for mitigation option evaluation

Identification of possible management alternatives to reduce entanglements in fishing gear can be aided through a quantitative assessment of the various options. Lebon & Kelly (2019) undertook such an assessment in response to a dramatic increase in humpback whale entanglements in Dungeness crab (*Metacarcinus magister*) fishery off US west coast. Management alternatives were compared using a multi-criterion decision analysis looking at estimated cost to fishermen, likely technical effectiveness, and anticipated reaction of fishermen in response to the change (a proxy for political feasibility). Through this process they identified galvanic timed releases as the highest ranking alternative. These devices have a low, one-time purchase cost, reduce whale entanglement through removing rope from the water column and fishers were not resistant to their use. Additional measures which ranked highly were reduction in line length, acoustic release devices, seafood certification programmes and derelict pot buybacks. By contrast whale pingers were ranked lowest with their high estimated cost of implementation, low likelihood of success and potentially high level of resistance from fishers.

An evaluation of previous and current programs to mitigate cetacean bycatch in artisanal fisheries in Ecuador was undertaken by Alavla et al. (2019). With the expansion of such fisheries, there is a critical need to understand the extent of cetacean bycatch by these fishers. Currently there is a lack of government interest, which would be necessary to document the extent of the problem both spatially and temporally. With potential resistance to top-down management arrangements perceived by fishers to have adverse economic impacts, Alavla et al. (2019) proposed a successful integration of mitigation strategies through bottom-up strategies, with fishers being integral in the provision of suitable measures. This is a complex issue with competing economic, social and cultural considerations to ensure fishers are willing to collaborate and comply. Nonetheless, integration of local communities into addressing the issue of cetacean entanglement is a critical success factor.

3.3.4 Evaluation of mitigation options

3.3.4.1 Gear modifications

Two work programmes described gear modifications implemented to reduce whale entanglements and associated mortalities.

Gear modifications and management arrangements designed to reduce entanglements of humpback whales in the commercial fishery targeting western rock lobster were implemented during 2014 in Western Australia (WA). This was in response to a dramatic increase in entanglements from 2011 through 2013, which coincided with a shift in the management of the West Coast Rock Lobster Managed Fishery to quota management and year-round fishing. This extension of the fishing season saw an increased temporal overlap with migrating humpback whales off the WA coast.

A statistical assessment of gear modifications showed that these significantly reduced the number of whale entanglements, with a median effect of 64% reduction (How et al. 2021). Measures included eliminated surface rope (top 1/3 held vertical in the water column through a weighted component to the line), shortened rope lengths (maximum of twice the water depth), reduced float numbers (maximum of three floats, two in water depths less than 55 m), and restrictions on soak times (maximum of seven days). Some of these arrangements were relaxed in shallower water (typically < 20 m) to encourage fishers to fish in areas where interactions with whales was less likely.

This work provides one of the few examples worldwide that statistically demonstrates the effectiveness of gear modifications, which were implemented quickly in response to government and social pressure. The success of the management arrangements was due to rapid uptake by fishers, facilitated by a strong outreach and compliance programme.

In the second work programme, modifications to gear comprising weak inserts and line were approved as part of the 2021 Atlantic Large Whale Take Reduction Plan for implementation from 2022. The new requirements apply to the US northeast lobster (*Homarus americanus*)/Jonah crab (*Cancer borealis*) fishery[6]. Requirements were finalised following lab-based testing of the breaking strengths of various ropes. To be approved for use in the fishery, rope breaking strengths were required to be 1,700 lbs ±10%. Approved three-strand ropes may be spliced into traditional ropes to create a weak insert. Approved braided ropes must be used as full ropes (not inserts). Insertion/attachment points are specified by the regulatory regime. Weak links comprising plastic rings are also regulated in this fishery and these must be marked with the breaking strain and installed in gear as specified. As these are new requirements in place from 2022, results on performance with respect to managing entanglements are not yet available.

3.3.4.2 Acoustic Deterrents

There have been two recent studies which have compared acoustic deterrents as a potential mitigation device, for humpback whales in particular. Basran et al. (2020) tested Future Oceans whale pingers and Lofitech seal scarers in the presence of feeding humpback whales off Iceland. Behavioural responses such as a reduction or cessation of surface feeding and an increase in swimming speed were noted as a response to pinger exposure. However, similar responses occurred when whales were exposed to other anthropogenic noises (e.g. sonar sounds, ship noise and approaches from whale watching vessels). Whales were also able to extricate themselves through a gap in a net which was fitted with whale pingers. Such a device may be useful as a mitigation measure for whales foraging around fishing activities. However, findings were tempered with caution regarding the widespread adoption of pingers. This caution was due to the potential for detrimental impacts at a population and individual level, through increased energy expenditure from faster swimming and a reduction in feeding.

Two different whale specific acoustic alarms were examined by How et al. (2020a). The Future Oceans F3 and Fishtek Banana acoustic alarms were characterised with the Future Oceans F3 field tested in the presence of migrating humpback whales off Geographe Bay, Western Australia. There was considerable variation in the performance across the >50 F3 alarms which were tested, resulting in the grouping of alarms based on their source level (SL). Soft, medium and loud (mean SL of 115, 122 and 129 re 1 μPa respectively) alarms were placed in separate arrays of modified gear through which 18 groups of whales were observed and tracked (the "focal follow" method). Seven groups were tracked while alarms were off while 11 were tracked while alarms were actively pinging. There was no evidence of whales interacting with or avoiding the gear at any stage during the trial, indicating that whales were capable of negotiating the gear without becoming entangled whether alarms were present or not.

[6] https://www.fisheries.noaa.gov/new-england-mid-atlantic/marine-mammal-protection/approved-weak-inserts-and-line-atlantic-large [Accessed 14 May 2022]

3.3.4.3 Ropeless Fishing

Three recent publications addressed ropeless fishing. This term describes gear setup in which the vertical buoy line used to mark and retrieve pots/traps is replaced with a submerged system. These systems are then remotely activated such that the vertical line or the pot/trap itself is released to the surface such that it can be retrieved.

Baumgartner et al. (2019) provided an overview of this system and the need for associated remote marking of gear to reduce gear conflict where fishers could place pots over another fishers' gear. He also noted that such gear use was illegal in most US trap fisheries, and that this needs to be addressed to permit its development. Greater development, and a requirement for this gear to be used in certain areas (where whales aggregate) or fisheries (whale-safe fisheries) would ultimately reduce unit costs and lead to greater uptake by fishers more broadly.

A workshop focused on this technology 'First annual Ropeless Consortium meeting' which occurred in New Bedford, Massachusetts (USA) in November 2018 was documented by Myers et al. (2019). The meeting included almost 100 participants: fishers, scientists, regulators, conservationists, engineers and manufacturers of ropeless fishing technologies. The meeting objectives were to '(1) *discuss the need for and approaches to implementing ropeless fishing to reduce entanglements of large whales in trap/pot fisheries*, (2) *discuss how to develop regulatory pathways to make ropeless fishing legal in the U.S. and Canada*, and (3) *discuss strategies to fund two phases of development: demonstration/evaluation and experimental fisheries*.' The report details the outcomes of developments in these areas and highlights the need for continued action in the development of this mitigation option.

Finally on ropeless fishing, Moore (2019) provided a 'Food for Thought' opinion piece, which focused on the need to engage the public in facilitating a move to ropeless fishing to mitigate entanglements. This highlighted the increasing recognition of bycatch related issues in sustainability assessments (e.g. Marine Stewardship Council[7]), and that greater public engagement is required to create a stronger financial incentive for fishers to adopt measures which reduce their environmental impact (in this case, whale entanglements).

3.3.4.4 Changes in Fishing Effort or Closures

Changes in fishing effort can be a result of management changes (e.g. closures) or other effort restrictions (e.g. pot usage rates), in response to market or biological/ecological factors. Such shifts can, depending on the cause of the shift, result in a reduced or increased spatio-temporal overlap between fishing activity and large cetaceans. Two recent publications examined a change in fishing effort from whale-related spatio-temporal closures, or a delayed start to fishing resulting from ecological factors.

Closures serve to remove/reduce fishing pressure from areas of whale occurrence (typically where whales occur in higher densities) to mitigate entanglement risk. Where all fishing grounds are not excluded (i.e. spatially explicit closures compared to complete fishery closures), fishing effort will be displaced to other open and fishable areas. Such temporally specific closures were implemented in the Gulf of St Lawrence snow crab (*Chionoecetes opilio*) fishery in Canada to mitigate against an increase in entanglements and mortality of the highly endangered North Atlantic right whale. Cole et al. (2021) evaluated the change in fishery dynamics from time-area closures, modelling the predicted response of fishers to displaced effort. While the closure resulted in an absence of fishing effort in the protected area, there was an increased risk of entanglement through increased fishing effort in areas outside of the closure. The pattern of displacement wasn't well predicted and led to a higher entanglement risk in otherwise low risk

[7] msc.org [Accessed 14 May 2022]

areas. The study highlighted the need to understand effort displacement resulting from fisher behaviour, and the dynamic nature of often highly mobile cetacean species. Similarly, time-area closures in the absence of other effort controls can lead to an increase in overall effort relative to catch, through fishing occurring in less productive grounds.

On the US West Coast, fishing was delayed during the 2016 Dungeness crab fishing season due to a harmful algal bloom (Feist et al. 2021). This resulted in a marked increase in fishing effort in the spring once the fishery opened. The opening of the fishery coincided with when humpback whales were foraging, after returning from their winter migration to the breeding grounds. Typically, the majority of Dungeness crab fishing is completed prior to spring, before the arrival of whales. This detailed examination by Feist et al. (2021) of fishing patterns in the Dungeness crab fishery, as well as several other fisheries in the area, indicated that there were no other major shifts in effort which would have resulted in the prolonged increase in entanglements which began in 2014. While the delayed start impacted entanglement numbers in 2016, it was coupled with a larger habitat compression in the area (see section 3.3.4.6 Ecosystem Shifts).

3.3.4.5 Understanding Migration Dynamics

Knowledge of the temporal and spatial components of whale migration or behaviour can assist in informing application of various management approaches. For example, the simple removal of fishing effort when whales are present can eliminate whale entanglements. However, for this to be effective, it requires an understanding of when whales are present in the fishing grounds as well as interannual variation in their presence.

How et al. (2020a) undertook an assessment of available data sources in conjunction with an extensive satellite tracking program to provide temporal and spatial data on humpback whale use of the West Australian coast. Multiple data sources (commercial whale watching records, citizen science sightings and satellite tagging) revealed that humpback whales frequent the WA coast between April – November annually. While broadly consistent across years, there was an interannual temporal shift apparent in the peak of the migration, with recent years indicating an earlier arrival. Satellite tracking also indicated that local oceanographic conditions (specifically the Leeuwin Current) may impact the spatial component of the migration and therefore the extent of interaction between migrating whales and fishing gear.

3.3.4.6 Ecosystem Shifts

The increased reported entanglements of predominantly humpback whales off the northeast Pacific of the USA was linked to an unprecedented marine heatwave that occurred in the California Current Large Marine Ecosystem during 2014-2016. Santora et al. (2020) demonstrated that the compression of cool seawater resulted in a change in the availability of krill (Euphausiacea) and anchovies (*Engraulis mordax*), two prey taxa for whales foraging in the area. A reduction of krill in offshore waters and greater anchovy abundance in the nearshore resulted in prey-shifting behaviour in whales, that moved into more coastal areas to forage on anchovies. This resulted in increased spatial overlap of foraging whales with commercial fishing gear. A delay to the opening of the fishery due to a toxic diatom bloom during the 2015-16 season also increased temporal overlap, with greater fishing effort coincident with greater whale abundances. Under changing climatic conditions, understanding the drivers of spatio-temporal abundance of whales can inform understanding and management of entanglement risks for fisheries (which could be mitigated through adjustments to fishing activities, for example). Additionally, as there is often some predicative capacity in oceanographic modelling, it provides an opportunity for proactive as opposed to reactive actions.

3.3.4.7 Mitigation reviews

Finally, three review papers were published during the focal time period. Hamilton & Baker (2019) and Tremblay-Boyer & Berkenbusch (2020) reviewed marine mammal bycatch in commercial trawl, purse seine, longline, gillnet and pot/trap fisheries. These were broad reviews that included pinniped and small cetaceans as well as large whale entanglements.

Regarding large whale entanglements, Hamilton & Baker (2019) noted that there is a need for urgent attention, with promising research being conducted in ropeless fishing and rope colours which may be more detectable to whales. A similar conclusion was reported by Stevens (2021) who examined the ecological impacts of traps, on both benthic and pelagic resources. They grouped mitigation options into three categories 1) modified fishing gear, 2) reducing lines in the water (effort) and 3) reducing encounters (time area closures), ultimately also highlighting the advantages of remotely activated ropeless gear.

Tremblay-Boyer & Berkenbusch (2020) focused on marine mammal bycatch in the New Zealand context in their recommendations. They emphasise that robust monitoring is essential for detecting fishery interactions, and note the challenges associated with testing mitigation approaches. Further, they reflect that effective mitigation methods are often fishery- and/or taxon-specific.

3.4 Workshop findings

After scene-setting presentations, workshop break-out discussion groups were formed. These groups provided feedback about a range of topics relating to entanglement risks and issues, and mitigation options. Key discussion points relevant to entanglement risks included drivers for fishing effort peaks and the feasibility of changing operations (Table 2). In relation to gear changes, operational impacts and the cost of mitigation measures were key points (Table 3).

Potential areas for further short-term work that were identified by workshop participants included:

- Improving knowledge and understanding of whale migration corridors, how these may change year to year and what drives changes
- Sharing whale sightings among vessel operators to heighten awareness of risks in real/near-real time (e.g., whale watch operations, DOC information on humpback whale migration onset, NZ RLIC using OceanSnap when development is completed)
- Increasing awareness of risk-reduction approaches across sectors fishing for rock lobster (e.g. minimising slack ropes, removing pots when not fishing, etc.).

Table 2. Summary of workshop breakout group discussion on fishing operations that may affect entanglement risk.

Discussion points	Group feedback

• What drives fishing effort peaks in NZ?
  ◦ CRA5 in May
  ◦ CRA2, CRA8 in Sept/Oct
	• In CRA 5, biological and market factors contribute to effort peaking in May
	  ◦ Lobsters are mating in March/April and moulting in late June/July
	  ◦ Abundance, price (export market) support May peak.
	  ◦ Males are considered more robust for export at this time.
	• Sept/Oct peak as female lobsters are out of berry (i.e., available to the fishery having released their eggs)
	• Market drivers affect the level of fishing activity year-round (demand, price)

• What is the feasibility of moving fishing effort in space and/or time? ◦ e.g. during high risk periods for entanglements	• Avoidance of seasonal closures is strongly preferred (to provide greater flexibility to meet market demands). • While the general migration period is known, whale migration timing varies slightly year to year, making precise adaptation of fishing operations difficult. • Commercial operators want to minimise fishing in summer when recreational sector activity (competition for catch and space, and potential for interference with gear) is high. • Fishing patterns variable, but generally gear set in 40 m or less of water. Often < 20 m and whales are further offshore (e.g. edge of continental shelf). • Gear in shallow water can move considerably, e.g. with waves, tides and weather events.
• What influences soak time (is a cap on soak time feasible?)	• Soak time is variable in different locations and among operators. • Support for removing pots from water when not fishing. Some fishers may remove gear in June/July. CRA2 and CRA 8 remove gear at season end.
• Is a maximum number of pots and ropes in the water feasible to manage? ◦ Are pot strings (i.e. lines of pots) feasible?	• Mixed views on a maximum number of pots in an area. Not supported by most. Potential for impacts on efficiency and fishing when market price is good. • Has been effort reduction due to improved catch rates. Pot lines chaff in deeper water and strings were considered impractical on foul ground. • Pot strings are in use over sandy bottoms for packhorse target fishing (in northern NZ).
• Other potential approaches	• Providing info on whale sightings especially around migration periods (e.g. when whales start moving through) would be helpful. Whale Watch operators do this for CRA 5. NZ RLIC can disseminate if received. • NZ RLIC's OceanSnap app will be used to collect information. Some technical issues with the app to date that will be resolved and progressed. • In northern NZ, whale watching permits issued by DOC include the requirement to report certain information including sightings. This can also be applied in other areas as DOC permits whale watch operations around the country.

	• Whales may come through in waves, e.g., pulses 2-3 week apart. Juvenile humpbacks may lag behind the main migration and may occur closer to shore than adults. • Need to know migratory corridors including interannual changes. • Ensure collaborative relationships are in place between industry and DOC's disentanglement teams.

Table 3. Summary of workshop breakout group discussion on gear modifications that may affect entanglement risk.

Discussion points	Group feedback
• Changing rope length	• When fishing in < 20 m use ~30 m ropes (less than 2 x water depth)
• Minimising the amount of slack surface rope	• Support minimising the amount of slack rope (this is already considered to be common practice by industry). • Coiling and leaving floating less effective at reducing risk compared to removing slack rope ('dog-boning'). Orca play with slack ropes which can result in entanglements.
• Changing float usage/Gear with submerged ropes ("ropeless" gear)	• Ropeless gear considered too expensive for current use and some vessels are small (e.g. estimate of market entry price for one type of ropeless gear AU$2,100 - $2,600 per release unit with prices expected to decrease over time and AU$8,500 base price for the deck unit with optional upgrades possible and (J. Fiotakis and M. Shegog, pers. comm.)). • Galvanic releases much cheaper per unit; would need to confirm pop-up time suits operation (operators would also consider cumulative costs, e.g., operators setting 80 – 100 pots per day) • Movement of gear in shallow water makes submerged gear usage problematic.
• Other potential approaches	• Regulation of floats, buoys used by recreational sector is lacking. • Recreational fisher education on reducing slack ropes/poorly fitted gear (e.g. insufficient ballast causing pots to move considerably). • Understanding risk by sector informative. Could recreational sector, e.g., be required to use one colour/size of rope, to facilitate this understanding? • Risks associated with ghost gear (are lost pots missed/recorded/reported anywhere?)

4. Discussion

4.1 Pot fishing activity in New Zealand waters

Understanding fishing effort in space and time is critical for understanding cetacean entanglement risks. Over time (including the period since the work of Laverick et al. (2017)), effort targeting rock lobster has comprised the significant majority of pot fishing in New Zealand waters. Relatively higher numbers of pot lifts targeting rock lobster continue to broadly coincide with humpback whale migration in key areas (e.g. Kaikoura to Cook Strait) as reported in Laverick et al. (2017). While fishing effort targeting other species is significantly lower, this does not eliminate entanglement risk. Further, interest in pot fishing for ling is growing with additional operators gearing up to use this fishing method (J. Cleal, pers. comm.), potentially increasing entanglement risk.

Compared to that considered by Laverick et al. (2017), the resolution of fishing effort information provided by ER enables a significantly improved characterisation of fishing patterns. Fishing effort information is available at a level of spatial and temporal detail now superior to the information available on the distribution of cetacean species (e.g. collated in Berkenbusch et al. 2013). This constrains the depth of analysis of entanglement risk that is possible, and collection of additional information on cetacean distribution (spatial and temporal) is discussed further below.

As well as the location of pot fishing effort, ER requires pot soak time to be reported. The frequency with which pots are visited and lifted may affect the detection of entanglements, when entangled animals and gear remain near the pot setting site. The time series of soak time information is still short due to the relatively recent introduction of this reporting requirement. Investigation of how fishers are reporting this information is recommended, as there may be spurious soak time values among recorded the data. For this project, we have presented soak time information as per the dataset. We could not empirically determine the number of hours beyond which records would be invalid. Further, the number of records above 200 hours, for example, was relatively small. Therefore, the broad patterns shown by the exploratory analyses presented in this report would be largely unaffected by erroneous high values.

Pot soak times varied between and within target species, e.g., total soak times for hagfish were notably shorter than other species (noting that in some areas there were missing soak time records for this species and paddle crab). As information on soak time accumulates over time, this is expected to be increasingly informative. Nonetheless, the information already available provides a broad basis for evaluating the feasibility of measures to manage and mitigate entanglement risks (e.g., galvanic timed release devices).

By combining effort (the number of pots lifted) with the soak time (how long pots are in the water) we can gain an understanding of the amount of rope in the water (rope hours), and therefore the potential entanglement threat. Using the available data, rope hours were relatively lower per one-degree square, but also more spread out geographically, in the months of May and June (noting the June entanglement peak). As an indicator of entanglement risk, we recommend considering this metric in future (e.g. after five years) as the length and quality of the soak time dataset increases. Rope hours is also likely to be a useful indicator for exploring entanglement risks as more information becomes available on cetacean distribution in space and time.

4.2 Cetacean entanglements in New Zealand

Cetacean entanglements have been recorded at an average rate of one to two per year since 1980, with notable peaks in several years. Predictably, reporting is more common in more recent years with 63% of entanglements recorded through 2010 – 2020, and an average rate of 4.7 records per year in that period. In other jurisdictions, higher rates have been reported, e.g. up to 31 entanglements per year in Western Australia (How et al. 2020a), and an average of 10 and a peak of 50 entanglements per year for the US West Coast states (Oregon, California and Washington; Santora et al. 2020). Reports submitted to the International Whaling Commission for the year 2021 included 42 and 29 entanglements in Australia and Mexico, respectively. By contrast, two were reported from New Zealand for the same year (IWC 2022).

Entanglements are detected opportunistically. It is expected that not all entanglements detected are reported to DOC. When known to DOC, entanglement event information must be captured in an appropriate database to create an enduring record. Overall therefore, the true extent of entanglements remains unknown and it is almost certain that more entanglements occur than the available records show. Challenges with detecting and under-reporting of entanglements events are well recognised in other jurisdictions (e.g., Tulloch et al. 2019; Ramp et al. 2021; Tackaberry et al. 2022). Further, the location and the time at which an entangled animal is detected do not always reflect where/when the entanglement occurred. Entangled cetaceans can carry gear significant distances. For example, one humpback whale reported entangled from Kaikoura in May 2020 and carrying gear marked with the identifying details of two vessels that operate in that area, was seen again and disentangled in July 2020 off New South Wales, Australia (DOC, unpubl.[8]).

Despite the limitations of the information available on entanglements in New Zealand, broad conclusions on risks and trends can be drawn. Entanglement reports continue to arise largely from the eastern coasts of the North and South Islands. Continuing the trends reported by Laverick et al. (2017), humpback whales remain the cetacean species most frequently reported entangled in New Zealand. Seasonality is evident in entanglement records. Humpback entanglements are reported throughout the year, peaking in June and October. These peaks are coincident with the species' northward and southward migration, respectively (Gibbs et al. 2018). Orca entanglements have been reported in the spring and summer months, with reports since 2017 again consistent with earlier findings (Laverick et al. 2017).

The number of humpback whales migrating through New Zealand waters appears to be increasing, suggesting entanglements are not driving a decline at the population level (Gibbs et al. 2018). Among other species reported from entanglement events since 2017, orca and Bryde's whale are classified as Nationally Critical in New Zealand (Baker et al. 2019). Therefore, losses due to entanglements are of more immediate concern at the population-level (while all entanglements invoke animal welfare concerns).

Records throughout the time series identify 'cray' fishing gear associated with entangled animals more often than other types of gear. This continued in recent years (76% of entanglement records since 2017). Verbal descriptions and photographs of entangling gear (stored with the entanglement records) would assist with verification of the source fishery (e.g. recreational or commercial, rock lobster or other pot fishery). Over time, such verification will contribute to an improved understanding of fishery interaction risks and issues. Nonetheless, the apparent preponderance of interactions with rock lobster gear among entanglement records, large amount of targeted rock lobster pot fishing effort, and spatial and temporal overlaps in fishing effort and humpback whale migration, suggest this fishery is a valid initial focus for management and mitigation efforts. Where entanglements are occurring, reducing these would reduce gear loss from the fishery and the associated costs of replacing lost gear. In context however, replacement gear costs due to entanglement are considered immaterial compared to storm-related gear loss and pots lost due to boat propellers cutting through buoy lines, precluding pot relocation and recovery (M. Edwards, pers. comm.).

While noting the dominance of effort targeting rock lobster among pot fisheries in New Zealand, the entanglement risks cannot be ignored in other pot fisheries. Cetacean distributions are broad and not well understood for most species. The probability of any cetacean encountering and becoming entangled in a pot line is low but not zero. Similarly in Western Australia, humpback whale entanglements have typically been associated with rock lobster fishing (e.g. How et al. 2020a). Nonetheless, three humpback whale entanglements with deep sea crab pot fishing gear have been detected (2014, 2020 and 2021). The deep-sea crab fishery operates at

[8] https://www.facebook.com/watch/?v=906814566500217 [Accessed 1 May 2022]

400 – 800 m. Fewer than 100 vertical pot lines are in the water at any time, due to the use of extensive strings of pots (e.g. approximately 200 pots per string, called pots per longline in this fishery). Humpback whales are generally thought to migrate along the 200 m isobath (Daume et al. 2021; Department of Primary Industries and Regional Development (WA), unpubl.). The likelihood of an entanglement occurring in this fishery appears infinitesimal, yet three are known to have occurred. Such events reinforce the importance of maintaining fisher awareness of entanglement risks across New Zealand pot fisheries (e.g. Deepwater Group 2020).

To improve the understanding of cetacean entanglement risks and provide a basis for more targeted management, additional work to collect, record and make available cetacean distribution information is strongly recommended. Structured surveys and citizen science initiatives both have potential value in this regard, given the long coastline in New Zealand and considerable resources required for scientific research on cetacean distribution at any scale. Citizen science initiatives are most likely to provide information from coastal areas and around human population centres. Nonetheless, the value of both approaches has been demonstrated in New Zealand and elsewhere (Tonachella et al. 2012; Embling et al. 2015; Currie et al. 2018; Gibbs et al. 2018; Garcia Segara et al. 2021). The nationwide Citizen Science Cetacean Census is a recent initiative that commenced in New Zealand in 2020. This programme was designed to occur during the northward migration of humpback whales and is now in its third year (https://www.facebook.com/groups/554312507954499). Regional initiatives include the Great Kaikoura Whale Count (https://www.facebook.com/TheGreatKaikouraWhaleCount/). Other sources of cetacean sightings information include commercial and recreational vessel operators (including fishers), and DOC-permitted cetacean-focused ecotourism operators. Collating and making available information collected from such initiatives is essential to maximising their value as a tool for improving knowledge of cetacean distribution. Documenting date and location (latitude/longitude) information and photos of animals seen will increase the value of such records.

Predictive modelling has been undertaken using the information that is available on cetacean distribution in New Zealand waters (Stephenson et al. 2020). At large spatial scales, oceanographic conditions were predictably correlated with cetacean distribution (e.g. temperature, depth). Research on individual species provides some information on smaller scale influences (e.g. seasonal prey abundance). However, there were more than 1,000 documented sightings available for only three taxa considered in Stephenson et al.'s (2020) work. Those taxa were Hector's, Māui and common dolphins. Seasonal and finer scale spatial and temporal distributions could not be considered. Improving cetacean distribution information would improve the outputs of such models. Further, in combination with the fishery data available, better assessments of fishery-related encounter and entanglement risks, explorations of risk factors (e.g. environmental factors affecting cetacean distribution), and the evaluation of management measures would become possible.

To improve reporting of entanglements by commercial fishers, an update of the cetacean codes listed in the ER circular is recommended. Some species that have been reported entangled in fishing gear are not currently listed, e.g. blue, sperm and Bryde's whales (Fisheries New Zealand 2021). Fishers may encounter entangled animals either with their own gear, or incidentally when on the water. It is recommended that species that are practicable for fishers to identify at sea, and that have been recorded in entanglement reports, are included in future updates of the circular.

4.3 Mitigation and management of cetacean entanglements

Recent literature on cetacean entanglement issues comprised either reviews of published information on mitigation methods, or publications reporting recent increases in reported whale entanglements in commercial fisheries and responses to those. A key difference between the New Zealand and international context that is clear from literature reviewed is the state of development of the entanglement issue. Among fisheries described in the literature, significantly more entanglements are detected than in New Zealand (see section 3.2 above). In most jurisdictions, rapid development and implementation of management measures has been required for regulatory, conservation, sustainability, or social licence reasons. By contrast, entanglements of large cetaceans in New Zealand pot fisheries are under management as an emerging issue. To date, this has provided the impetus to characterise the issue and explore mitigation options (Laverick et al. 2017, and this project), but not to progress the development of regulatory options.

Discussions at the workshop conducted as part of this project elicited a range of views from participants on the feasibility and applicability of mitigation and management approaches in the New Zealand rock lobster fishery. The consensus view of participants was that appropriate next steps included knowledge gathering (e.g. to better understand humpback migration pathways and the timing of migration), and increasing awareness of entanglement risks and ways to reduce those risks among both commercial and recreational sectors. Social licence impacts associated with entanglements were not considered significant to date.

Risk reduction measures that workshop participants considered would be appropriately implemented across the fishery were (noting that some fishers report already implementing these measures):

- Removal of pots from the water when not fishing
- Minimising the amount of slack rope attached to pots
- Improving gear rigs to minimise movement after setting.

Participation of industry operators in DOC disentanglement training sessions was also an identified future option for those interested.

Key concerns with more intensive management approaches were the cost of mitigation technology/devices and the ongoing flexibility for catch to be optimised with respect to market price, and for catch volumes to meet market demands (e.g. festive periods in export markets).

Considering stakeholder views and the information available, investigation of the use of galvanic releases in entanglement hotspots would be a useful next step where management agencies seek effective technical options to reduce entanglement risks. Limited use of pop-up activated buoy releases is occurring among pot fishers targeting packhorse and rock lobster in northern New Zealand. A key motivator for adoption of this system is unlawful interference with fishing gear (D. Webber, pers. comm.). Clarification of the Fisheries (Commercial Fishing) Regulations 2001 (regulation 56) may be required to confirm the legality of timed-release equipment on pot fishing gear, i.e., whether surface buoys or floats must be visible throughout pot sets. Galvanic releases could be investigated on a research basis (with closed unbaited pots) to assess broader feasibility in the first instance. These devices are commercially available (including in New Zealand[9]) pre-set for release at a range of timeframes (e.g. 1 – 14 days) and

[9] https://www.discountfishingsupplies.co.nz/shop/FISHING+SECTION/SALTWATER+FISHING+SECTION/Craypots/Craypot+Pop-Up+Timer+24hr%3Fsku=3748.html

ocean temperatures (e.g. 0 – 27°C)[10]. Custom-specified devices are also commercially available (e.g. with longer release times of up to 100 days)[11]. Price varies with device specifications, e.g., 50 units with a 1-day release time in seawater of 8.3-12.2°C retail online at USD$85[12]. Experimental testing in local conditions is expected to be worthwhile, e.g. to confirm release times are matched to local requirements. Research findings from other jurisdictions provide useful background for New Zealand-based investigations (Warren & Wooden 2020).

Similarly, trialling the use of rope segments is recommended, to reduce the amount of slack line present in the water column or coiled but not removed from the gear set (this coiling is known as dog-boning by New Zealand fishers). While reducing the length of slack rope in the water column, entanglement risk remains with the dog bone. Rope segments (Figure 39, left image) are used in other jurisdictions, to link ropes of different lengths into a single mainline (Figure 39, right image). Different sections can be removed or added according to the depth fished to minimise slack rope and entanglement risk.

Figure 39. Recovered gear from a whale entanglement in Western Australia, illustrating (L) the three sectional ropes (black, orange and yellow) comprising the mainline, and (R) the join used to combine sectional ropes.

4.5 Recommendations

Recommendations emerging from this project include approaches to building better understanding and supporting next steps for management of cetacean entanglement risks in New Zealand pot fisheries. These include:

Reporting

- Streamline the reporting of all entanglements nationwide, such that entanglement events are:
  - consistently reported to DOC
  - captured within an appropriate DOC database
  - recorded with unique information including date and latitude/longitude; and,
  - when possible, linked to photographs that allow identification of entangling materials and whale species (and verification of such identifications at future points in time).

[10] https://www.lpfishingsupply.com/products/galvanic-timed-release [Accessed 1 June 2022]
[11] https://www.underseareleases.com/timetempchart.htm [Accessed 1 June 2022]
[12] https://www.lpfishingsupply.com/products/galvanic-timed-release?variant=42283094158 [Accessed 1 June 2022]

- Maintain and grow relationships between fishing industry and other maritime operators and DOC disentanglement teams, and ensure reporting channels are clear (e.g. the phone number to use for entanglement reports), to facilitate the reporting of entanglement events and details critical to successful disentanglements, especially in entanglement hotspots.
- Update the NFPS reporting codes available to commercial fishers to include all cetacean taxa that are practically identifiable at sea that have been reported entangled to date.

<u>Spatial and temporal distribution of cetaceans</u>

- Build knowledge of cetacean distribution (spatial and temporal), through:
    - ongoing collection of sightings information
    - regular collation of sightings information (e.g. every five years)
    - characterising cetacean distributions in time and space; and,
    - ensuring this information is available for future work, such as identifying hotspots for entanglement risk.
- When information on cetacean distribution has improved (e.g. after five years), re-examine environmental factors that may influence cetacean distribution, including the timing of humpback migration and finer-scale determinants of migration pathways used, to better understand entanglement hotspots and risk factors.

<u>Understanding fishing practices</u>

- Characterise pot fishing gear used in New Zealand with an initial focus on gear used to target rock lobster, to provide a basis for any future assessment of the feasibility and impacts of gear-related mitigation measures (e.g. weak links, weighted buoy lines).
- Investigate the use of pot strings by some fishers in New Zealand, and international practices, to consider the broader applicability of this approach to reducing the number of vertical buoy lines present, and therefore entanglement risk.
- Investigate how fishers are reporting soak time, to ensure this is effectively representing fishing practices.

<u>Entanglement mitigation</u>

- Foster the adoption of mitigation measures already used by some fishers in the rock lobster fishery, i.e. removing pots from the water when not fishing and minimising slack ropes attached to pots.
- Trial the use of rope segments among willing operators, to reduce the amount of slack buoy line in the water and as an alternative to potentially entangling dog-boning of excess rope.
- Test galvanic timed releases for lobster pots on a small-scale research basis in local conditions in regions where orca and humpback entanglements are detected more frequently (e.g. northeast coast of the North Island in summer, and around Kaikoura in winter).
- Among pot fishers (including recreationalists), improve awareness of entanglement risks and issues, e.g. through near real time information sharing of whale sightings (such as is planned for OceanSnap) with best practices for entanglement risk reduction, codes of practice, recreational fishing apps, industry networks and social media channels during higher risk periods.
- Within the rock lobster industry, proactively identify a range of potential effective mitigation measures which could be practically implemented should a marked increase in reported entanglements occur.

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Figure 40. A humpback whale entangled in rock lobster fishing gear, photographed off Otago in 2019. (The unique vessel identifiers on the buoy have been blurred). Photo: W. Rayment, provided by DOC.

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Appendix 1: Summary of cetacean entanglement records

Common name	Scientific name	Date	Entangling material	Outcome	Location Description	Area/Region
Common dolphin	*Delphinus delphis*	2/07/1980	Fouled in craypot buoy line.	Dead.	E end of Whale Island, Whakatane	Bay of Plenty
Hector's dolphin	*Cephalorhynchus hectori*	16/01/1989	Caught in craypot line by flukes.	Dead.	Off Oaro	Kaikoura
Humpback whale	*Megaptera novaeangliae*	22/10/1994	Live entanglement; incidental to fishing.		100 m E of Pigeon Bay	Canterbury
Hector's dolphin	*Cephalorhynchus hectori*	15/01/1997	Caught by two loops of craypot lines by tail stock.	Dead.	South Bay, Kaikoura	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2000	Craypot rope.	Released.	Shark's Tooth	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2001	Craypot rope.		Conway	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2001	Craypot rope.		Shark's Tooth	Kaikoura
Humpback whale	*Megaptera novaeangliae*	7/06/2001	Live entanglement in craypot line.	Released alive.	N of Kaikoura	Kaikoura
Humpback whale	*Megaptera novaeangliae*	9/06/2001	Live entanglement in craypot line.	Released alive.	E of Kaikoura Peninsula	Kaikoura
Common dolphin	*Delphinus delphis*	29/08/2001	Recovered from net with approximately 2 m of 20 mm rope wrapped around tail fluke.	Dead.	Papa Aroha, 1 km N of camping ground	Waikato
Humpback whale	*Megaptera novaeangliae*	2002	Craypot rope.	Released.	Sharks Tooth	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2002	Craypot rope.		Mangamaunu	Kaikoura
Humpback whale	*Megaptera novaeangliae*	27/06/2002	Live entanglement; two craypot ropes.	Disentangled and released alive?	Mangamaunu	Kaikoura
Humpback whale	*Megaptera novaeangliae*	29/06/2002	Live; entangled in 2 craypot lines.	Partially disentangled; released alive.	Mangamaunu	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2003	Craypot rope.		Shark's Tooth	Kaikoura

Humpback whale	*Megaptera novaeangliae*	2003	Craypot rope.		Shark's Tooth	Kaikoura
Humpback whale	*Megaptera novaeangliae*	13/06/2003	Live; entangled in craypot line.	Partially disentangled; released.	Mouth of Conway River, then 500 m E of Kaikoura Peninsula	Kaikoura
Southern right whale	*Eubalaena australis*	27/07/2003	Live; entangled in craypot line.	Uncertain; appeared to be disentangling itself.	Bay S of Lord's River	Southland
Humpback whale	*Megaptera novaeangliae*	25/01/2004	Marks around midriff indicative of entanglement by rope.	Dead.	Shingle fans, N of Camp Stream	Kaikoura
Humpback whale	*Megaptera novaeangliae*	25/04/2004	Deep rope.	Dead.	Camp Stream	Clarence
Humpback whale	*Megaptera novaeangliae*	9/06/2004	Live entanglement.		Kaikoura	Kaikoura
Hector's dolphin	*Cephalorhynchus hectori*	2/08/2004	Entangled in commercial craypot line or floats.	Dead.	South Bay, Kaikoura	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2007	Craypot rope.		Kaikoura Peninsula	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2007	Craypot rope.		Shark's Tooth	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2008	Craypot rope.		Kowhai	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2008	Mono net.	Released.	Kowhai	Kaikoura
Blue whale	*Balaenoptera musculus*	26/05/2009	Quantity of rope in mouth, tailstock badly cut into.	Dead.	Te Hapu; cast on mudstone/limestone terrace against rock columns.	Tasman
Humpback whale	*Megaptera novaeangliae*	14/06/2009	Live entanglement in commercial fishing net.		Kaikoura	Kaikoura
Humpback whale	*Megaptera novaeangliae*	2010	Rope and net.	Released.	Northland	Bay of Islands
Humpback whale	*Megaptera novaeangliae*	2010	Light rope.		Northland	Bay of Islands
Humpback whale	*Megaptera novaeangliae*	2011	Craypot rope.	Self-released.	Lucky Point	Tory Channel

Humpback whale	*Megaptera novaeangliae*	2011	Craypot rope.		Banks Peninsula	Canterbury
Humpback whale	*Megaptera novaeangliae*	2011	Craypot rope.	Released.	Picton	Tory Channel
Orca	*Orcinus orca*	2011	Craypot rope.	Released.	South Bay	Kaikoura
Orca	*Orcinus orca*	17/02/2011	Entangled in craypot lines.	Released alive.	Barney's Rock, S of Kaikoura	Kaikoura
Humpback whale	*Megaptera novaeangliae*	16/03/2011	Tangled in craypot lines.	Released alive; whale condition poor; prognosis considered poor.	20 km S of Kaikoura, 4 km offshore	Kaikoura
Southern right whale*	*Eubalaena australis*	23/07/2011	Craypot rope.		St Kilda	Dunedin
Orca	*Orcinus orca*	2012	Craypot rope.	Released.	Hahei	Whitianga
Bottlenose dolphin	*Tursiops truncatus*	30/01/2012	Tail wrapped in commercial craypot and float.	Dead.	Taiharuru	Northland
Orca	*Orcinus orca*	7/02/2012	Entangled in craypot line.	Released alive.	Several hundred metres offshore between Hahei and Hot Water Beach	Waikato
Sperm whale	*Physeter marcrocephalus*	8/06/2012	Rope floats.		Red Mercury	Whitianga
Humpback whale	*Megaptera novaeangliae*	19/07/2012	Entangled in craypot line (orange float attached to rope crossing whale's back).	Self-released.	Close into shore; Kaikoura Peninsula	Kaikoura
Humpback whale	*Megaptera novaeangliae*	17/08/2012	Commercial net and rope gear; deep-set net.	Self-released.	Approximately 1 km off Haumuri Bluff	Kaikoura
Humpback whale	*Megaptera novaeangliae*	25/08/2012	Rope and chain.	Not seen again.	Tuhua Marine Reserve	Tauranga
Humpback whale	*Megaptera novaeangliae*	24/09/2012	Recreational craypot.	Released.	Shark's Tooth	Kaikoura
Orca	*Orcinus orca*	16/11/2012	Rock lobster entanglement.	Dead.	CRA Statistical Area 907	Bay of Plenty
Orca	*Orcinus orca*	20/11/2012	Entangled; craypot rope?	Dead.	Tauranga	Mayor Island
Orca	*Orcinus orca*	27/11/2012	Wrapped in crayfish pot line.	Dead.	SW of Mayor Island	Bay of Plenty
Humpback whale	*Megaptera novaeangliae*	18/05/2013	Craypot rope (12 mm).		Ngawi Bay	Wairarapa

Humpback whale	*Megaptera novaeangliae*	8/10/2013	Gill net and float.		Makatu Beach	Bay of Plenty
Humpback whale	*Megaptera novaeangliae*	17/10/2013	Rope and float		Nugget Point	Otago
Orca	*Orcinus orca*	2014	Craypot and rope.	Released.	Kawau Island	Hauraki Gulf
Orca	*Orcinus orca*	8/09/2014	Crayfish rope and buoy.	Released alive.	3 km offshore at the back of Fairchild Reef; 1 km E of Kawau Island	Hauraki Gulf
Humpback whale	*Megaptera novaeangliae*	30/10/2014	Craypot line around pectoral fin.	Self-released during attempted disentanglement.	Initially at Barney's Rock, then Shark's tooth, heading to Kowhai River	Kaikoura
Humpback whale	*Megaptera novaeangliae*	5/11/2014	Thick nylon triple-braided rope around tailstock.	Not seen again.	Approximately 1.3 km NE of Taiaroa Head	Otago
Humpback whale	*Megaptera novaeangliae*	28/11/2014	Cray pot rope.	Self-released.	Kaikoura Peninsula	Kaikoura
Humpback whale	*Megaptera novaeangliae*	21/06/2015	White polystyrene float trailing 15-20 m of 6.5 mm line behind whale.		Travelling N; S of Jordy Rocks	Marlborough
Humpback whale	*Megaptera novaeangliae*	24/06/2015	Two orange floats trailing 20 m behind whale.	Gear partially removed (buoys cut off).	First seen in a line with Cape Campbell. Heading inshore and N.	Marlborough
Humpback whale	*Megaptera novaeangliae*	21/07/2015	White 250 mm polystyrene float (250 mm) with 6.5 mm line through centre hole, line trailing 15 m behind whale.		Pelano Head, Arapawa Island	Cook Strait
Humpback whale	*Megaptera novaeangliae*	24/07/2015	Cray line 10 mm with two named orange floats attached.		NE of Cape Campbell, 5 nautical miles offshore	Cook Strait
Humpback whale	*Megaptera novaeangliae*	13/09/2015	Single rope through mouth, another over back, and multiple wraps around pectoral fin. Entangling gear identified as cray.	Disentangled; released.	Fitzroy Bay	Wellington
Orca	*Orcinus orca*	18/11/2015	Fisher found his previously lost craypot with entangled whale carcass attached by the tailstock.	Dead.	Outer Hauraki Gulf, near Middle Island	Waikato

Humpback whale	*Megaptera novaeangliae*	14/03/2016	Both sides of tail missing; considered evidence of previous entanglement.	Alive.	Kaikoura coast, Goose Bay	Canterbury
Orca	*Orcinus orca*	14/12/2016	Entangled in craypot line.	Released alive.	Off Tokoroa Rock at Kennedy Bay	Coromandel Peninsula
Pygmy right whale	*Caperea marginata*	13/02/2017	Entangled in craypot rope.	Dead.	"The Mucks" rocks on headland N of Horseshoe Bay	Stewart Island
Balaenoptera spp.	*Balaenoptera* spp.	19/02/2017	Entangled in craypot line with orange buoy.		Current Basin, French Pass	Marlborough
Humpback whale	*Megaptera novaeangliae*	24/06/2017	Entangled with green 10 mm poly line with two orange buoys attached trailing 15 m behind whale.	Gear partially removed (floats and 3.6 m of line)	NE of Cape Campbell, 5 nm offshore	Cook Strait
Humpback whale	*Megaptera novaeangliae*	6/09/2018	Entangled; unable to move freely.	Not seen again.	Kingfish reef, off Deepwater Cove, Bay of Islands	Northland
Humpback whale	*Megaptera novaeangliae*	21/10/2018	Entangled in craypot line.	Disentangled; released alive.	3 nm out to sea between Whangamata and Onemana	Waikato
Balaenoptera spp.	*Balaenoptera* spp.	26/01/2019	Entangled in rope with cray line type floats around the body.	Gear partially removed (except line running through mouth). Not seen again.	12 nm NE of Great Barrier Island	Hauraki Gulf
Humpback whale	*Megaptera novaeangliae*	28/03/2019	Entangled in crayfish pot rope and float; 4 wraps around tailstock and flukes. Rope around left flipper appeared to lead to mouth.	Disentangled; released alive.	Off Otago coastline	Otago
Humpback whale	*Megaptera novaeangliae*	22/06/2019	Thought to be craypot line wrapped around pectoral fin and tailstock; trailing 20 to 30 m of line.	Not seen again.	Knife and Steel Harbour, Waitutu	Southland
Humpback whale	*Megaptera novaeangliae*	2/07/2019	Rope around tailstock, flukes; pots in the area but no floats observed on the animal.	Likely to have self-released.	Off Kaikoura Peninsula	Kaikoura
Orca	*Orcinus orca*	14/09/2019	Craypot line around base of pectoral fin.	Released alive.	Between Kawau Island and Elephant Point (SE corner of Tawharanui Peninsula)	Hauraki Gulf

Humpback whale	*Megaptera novaeangliae*	7/10/2019	Entanglement in pot gear.	Self-released.	Off Kaikoura Peninsula	Kaikoura
Southern right whale (1)	*Eubalaena australis*	7/11/2019	Commercial fisher NFPS bycatch report		Near Anchor Island	Fiordland
Southern right whale (2)	*Eubalaena australis*	7/11/2019	Commercial fisher NFPS bycatch report		Near Anchor Island	Fiordland
Orca	*Orcinus orca*	24/12/2019	Entanglement in craypot line.	Partially disentangled; not seen again.	Originally spotted near Tutukaka, swam S to Waiheke Island	Northland
Southern right whale	*Southern Right whale*	1/05/2020	Commercial fisher NFPS bycatch report		South Bay, Kaikoura	Kaikoura
Humpback whale	*Megaptera novaeangliae*	22/05/2020	Entangled in craypot line around pectoral fin.	Disentangled in July off New South Wales.	Off Kaikoura	Kaikoura
Bryde's whale	*Balaenoptera edeni*	9/03/2022	Entangled in fishing gear.	Disentangled; released alive.	Great Mercury Island (SW side, facing Coromandel Peninsula)	Coromandel Peninsula
Hector's dolphin	*Cephalorhynchus hectori*	14/03/2022	Entangled in craypot rope and buoys.	Released alive.	Haylocks Bay, Akaroa	Canterbury

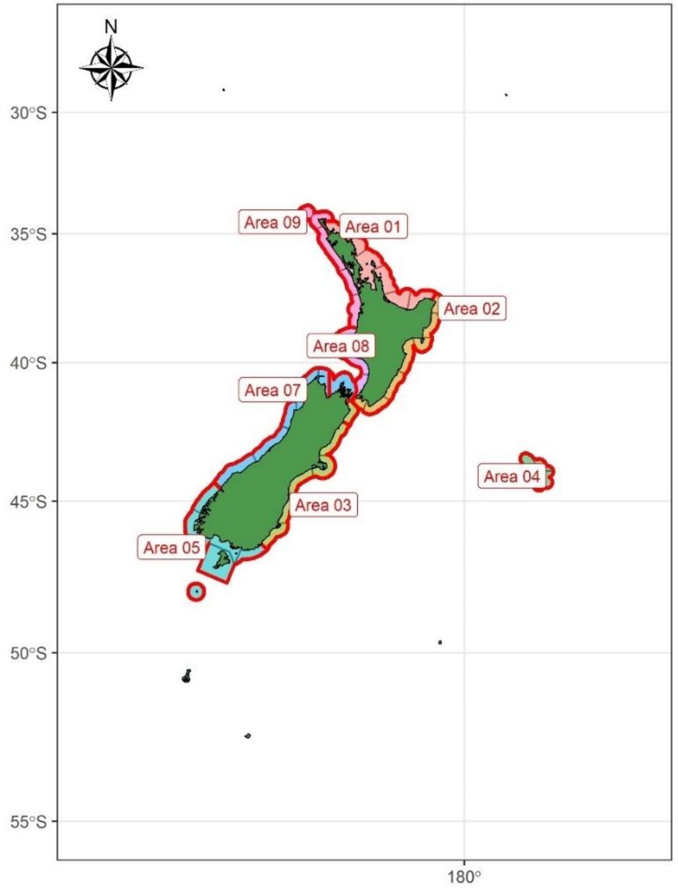
*: Identification uncertain

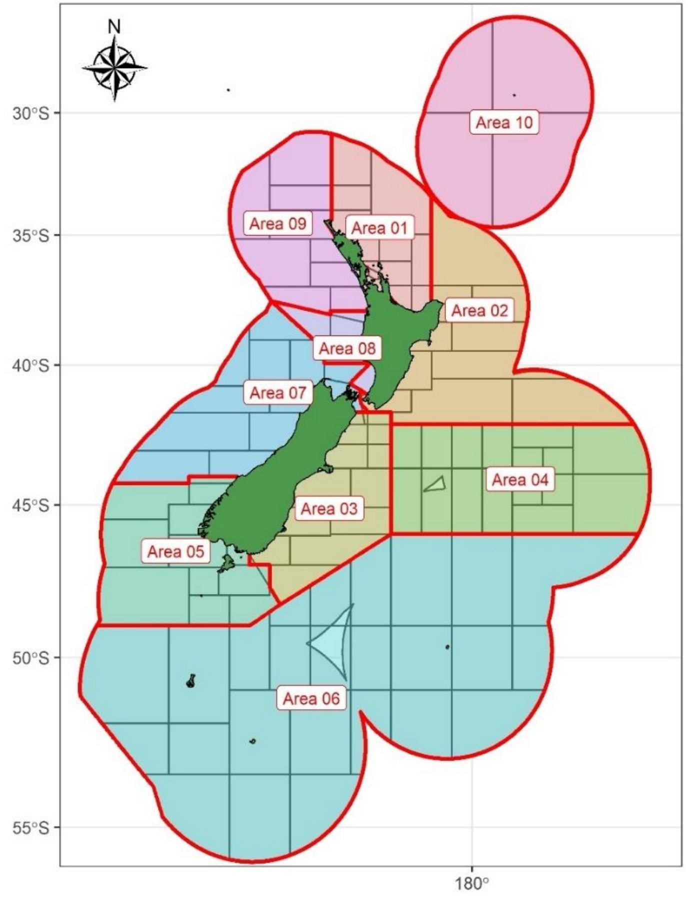
Appendix 2: Workshop participants

* indicates workshop presenters

Johanna Pierre	Project team
Jason How*	Project team
Alistair Dunn	Project team
Dan McRae	Fisher (CRA 2, Hauraki Gulf)
Paul Reinke	Fisher (CRA 5, off Kaikoura)
Peter Cleall	Fisher (CRA 5, off Kaikoura)
Jamie Reinke	Fisher (CRA 5, off Kaikoura)
Andrew Sim	Fisher (CRA 4, off Napier)
James Robertson	New Zealand Rock Lobster Industry Council
Mark Edwards	New Zealand Rock Lobster Industry Council
Jules Hills	New Zealand Rock Lobster Industry Council
Malcolm Lawson	CRA 8 Rock Lobster Industry Association
Larnce Wichman	CRAMAC 5 Association
Rob Chappell	Disentanglement expert consultant
John Edwards*	Parks and Wildlife Service, Department of Biodiversity, Conservation and Attractions, Western Australia
John Fiotakis*	Fiomarine Industries
Mike Shegog*	Fiomarine Industries
Geoff Liggins*	Department of Primary Industries, New South Wales
Shannon Weaver	Department of Conservation (Bycatch Programme Coordinator)
Catherine Peters	Department of Conservation (New Zealand Disentanglement Team Lead: North Island)
Jody Weir	Department of Conservation (New Zealand Disentanglement Team Lead: South Island)

Appendix 3: Spatial allocation of fishing catch and effort data





Areas approximating New Zealand Fisheries Management Areas that are used to present some commercial fishery catch and effort information (as indicated in figure legends). L: Spatial boundaries used to group pot fishing effort targeting rock lobster (CRA) and catch; R: Spatial boundaries used to group pot fishing effort targeting all other species and catch.