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New Zealand billfish and gamefish tagging, 1997–98

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7. Executive Summary

In 1975, the then Ministry of Agriculture and Fisheries implemented a cooperative gamefish tagging programme at the request of angling groups. For the last two years, the Ministry of Fisheries has contracted the National Institute of Water and Atmospheric Research (NIWA) to maintain this programme with the help of angling clubs and commercial fishers. The attached report summarises reported tag recaptures and releases during the 1997–98 season.

During the 1997–98 season a total of 2549 tag report cards were returned to NIWA and 69 tagged fish were recaptured. As in previous seasons, the predominantly tagged species were striped marlin, kingfish, mako and blue sharks. The percentage of striped marlin tagged by participating clubs was 62%, which is a similar percentage to that observed in previous years. Despite fewer striped marlin being tagged this season than in the previous two seasons, there have been a record number of recaptures. Eleven recaptures were reported, compared with 29 for all seasons combined since the programme began.

Striped marlin, mako and blue sharks are often recaptured following migration to the tropics although the majority of recaptures occur within New Zealand waters. Kingfish are usually caught close to the point of release. Growth rates of kingfish were also investigated this year using length increment data derived from the tagging programme and it appears that kingfish is a fast growing species. While these growth estimates are thought to be the best available, they should be treated with some caution as the growth model used suggested that measurement error was high.

Collaborative research recently undertaken to investigate the use of satellite and archival tagging techniques for estimating movement of billfish within and beyond New Zealand waters was reviewed. While the results of this study were of little value, a literature review of recent advances in intelligent tag technology suggests that this approach may provide effective means of assessing movement rates, patterns and post tagging survivorship of key billfish and gamefish species.

8. Objectives

1. To review the results of collaborative research into the use of satellite and archival tagging techniques for estimating movement of billfish within and beyond New Zealand's EEZ and the residence time of striped marlin in New Zealand waters, and to determine the requirements for further related collaborative research in 1998–99.

2. To determine the growth of kingfish from tagging data.

3. To determine the movement of kingfish and mako and blue sharks from tagging data.

4. To update the tagging database with the inclusion of data for the 1997/98 year.

9. Publications

Hartill, B. 1998: Best ever tagged marlin recaptures. New Zealand Fishing News No. 21 (11): 20-21.

10. Data Storage

Data from this season's tagging programme will be stored on the Ministry of Fisheries *tag* database, held by NIWA.

Introduction

In 1975, the New Zealand Ministry of Agriculture & Fisheries implemented a cooperative gamefish tagging programme at the request of angling groups. Historically, recreational fishers had tagged many gamefish, and high recovery rates of tagged fish promised to provide valuable information on growth and movement. Recreational anglers voluntarily reported all tag release and recapture information which was then stored on a database and analysed for fish movement and growth.

The programme became significant in the management of billfish species in 1988, when the Minister of Fisheries restricted access to the Auckland Fishery Management Area for foreign licensed tuna longline vessels and prohibited the retention of any commercially caught billfish, except swordfish, by domestic vessels in northern New Zealand waters. At the time, recreational fishers were encouraged to tag at least 50% of their catch to assist in assessing the distribution of striped marlin (*Tetrapturus audax*) and the degree of interaction with the commercial fishery.

A review of the programme in November 1991 determined that it has the potential to provide data useful for improving management of key recreational gamefish species, such as kingfish (*Seriola lalandi*), mako shark (*Isurus oxyrinchus*), and blue shark (*Prionace glauca*). The objective of tagging these species was to collect and analyse information on growth and movement. The overall results on billfish distribution and movement provide the Ministry of Fisheries with information to gauge the effectiveness of measures to reduce conflict between the recreational gamefish and commercial tuna longline fisheries.

In April and May 1996, the feasibility of tagging striped marlin using towed satellite tags was investigated by Ministry of Fisheries staff in conjunction with Barbara Block from Stanford University. This collaborative research was the first attempt to use satellite tags on New Zealand striped marlin. Although the results of this trial were disappointing, recent literature suggests that advances in tagging technology may provide cost effective methods of assessing management issues such as post tagging mortality and the degree of user group conflict. Satellite tagging may also help to explain factors influencing net movement trends observed using conventional tagging techniques.

Kingfish (*Seriola lalandi*) is an important species for both the recreational and commercial fisheries in the Auckland area and was ranked 5th in terms of the number of recreational fishers who caught this species in 1987 (Sylvester *et al.* 1994). Estimating growth rate is important for describing productivity, and hence sustainable yields for a species. Since 1978 a large amount of incremental growth data has been collected from kingfish tagged and recaptured as part of this programme. This data may provide the best available means for estimating kingfish growth.

Specifically, the programme objectives for 1997–98 were as follows:

1. To review the results of collaborative research into the use of satellite and archival tagging techniques for estimating movement of billfish within and beyond New Zealand's EEZ and the residence time of striped marlin in New Zealand waters, and to determine the requirements for further related collaborative research in 1998–99.

2. To determine the growth of kingfish from tagging data.

3. To determine the movement of kingfish and mako and blue sharks from tagging data.

4. To update the tagging database with the inclusion of data for the 1997/98 year.

This report summarises the results obtained from the tagging programme from 1 July 1997 to 30 June 1998. The project was carried out on contract to the Ministry of Fisheries (project number BIL9801).

Methods

Billfish and gamefish were tagged through the existing cooperative arrangement with recreational and commercial fishers who voluntarily tag and release billfish and gamefish species. This cooperative arrangement with anglers and commercial fishermen formed the basis for the tagging, releasing and recapturing of tagged gamefish and billfish during 1997–98. The distribution of tags to recreational fishing clubs through the New Zealand Big Game Fishing Council (NZBGFC) and the tagging methodology has been described by Saul & Holdsworth (1992). A brief outline of the tag type and methodology follows.

As in previous years fish were tagged with a visual implant tag, as described by Davies & Hartill (1998). The New Zealand Big Game Fishing Council distributed over 6000 tags to gamefish clubs and participating anglers before, and during, the 1997–98 billfish season (October–April). Tags were also supplied to commercial fishers by NIWA on an individual boat basis. Participants completed a fish tagging report card, recording relevant information on the release of a tagged fish and submitted it either through their clubs or directly to NIWA. All release details were entered into a regional tagging database which is archived on the central NIWA database in Wellington.

The message on the tag informs anglers that a reward will be offered for details of the recapture of tagged fish. These recapture details are then entered into the relational tagging database and added to the data from previous years.

For each species, tag release and recapture information was summarised in terms of size, the spatial and temporal distribution of releases and recaptures, and the respective catch by the recreational and commercial fishing sectors. Size distributions were categorised by 10 cm length intervals. The size of fish released or recaptured is given in terms of length and weight. Often these sizes are only estimates, especially when the fish is not landed. Length data in this report are based on, in order of preference, measured length, measured weight converted to length, estimated length, and estimated weight converted to length. Weights were converted to lengths using the best available length-weight relationships (Table 1). Blue shark lengths derived from weights were likely to be underestimates as they were based on a conversion to standard length as no conversion parameters were available for total length estimation. When lengths and weight estimates were reported, conversion of weight estimates using a standard length weight relationship resulted in length estimates which were similar to those reported by the fisher. As length estimates were given for 94% of the blue shark releases reported, the use of lengths derived from weights is unlikely to have had much influence on the length frequency presented.

The spatial distribution of release and recapture locations of tagged fish relative to broad areas of the New Zealand coast was summarised using Ministry of Fisheries commercial statistical reporting areas (Figure 1). Fine resolution plots of release locations for main species were produced from the information on the fish tagging report cards. The temporal distributions of releases and recaptures were categorised by calendar month. Releases and recaptures were categorised according to the commercial or recreational methods of capture.

Net movements of billfish, mako sharks, blue sharks and kingfish were determined from the release and recapture locations. The frequency of individual fish moving between statistical areas was tabulated to determine broad patterns in movement of mako shark, blue shark and kingfish. A detailed chart of the individual movements of recaptured striped marlin was produced.

Kingfish growth was estimated using a length-based maximum likelihood approach (GROTAG, Francis 1988) with a seasonal model component (Francis & Winstanley 1989). A major concern in fitting a growth model to the available data was the quality of the length and weight observations recorded by anglers on release or recapture. For many recaptures length or weight observations were based upon visual estimates rather than actual measurements. Sub-set 1 included all recaptures where length or weight was measured at both release and recapture (n=214). Sub-set 2 included sub-set 1, and all other recaptures where length or weight was measured once, either at release or recapture, with the other observation being a visual estimate (n=474). A range of models were investigated from fits to these sub-sets, and slight variations thereof. Where fish size on release or recapture was recorded as a weight, this was converted to length using an available length-weight relationship for New Zealand kingfish, (McGregor, in prep. Table 1).

Results

Striped marlin

Of the 880 striped marlin tagged and released by commercial and recreational fishers between 1 July 1997 and 30 June 1998 (Table 2), 876 were released by the recreational fishery (Appendix 1). This is the lowest number of marlin tagged and released in the last five years. As the total number of marlin caught by gamefish clubs, estimated from gamefish club records was 1414 (Ross Nelson, pers. comm.), 62% of all striped marlin caught during the 1997–98 season were tagged and released, compared with 68% in 1996–97 and 58% in 1995–96. Only 4 striped marlin were tagged and released by commercial fishers in 1997–98 (Appendix 2). These marlin were tagged off East Cape where relatively few striped marlin were tagged by recreational fishers.

A wide range of sizes of striped marlin was tagged and released with an estimated mean length of 226 cm (Figure 2a). The NZBGFC and member clubs encourage the tagging and releasing of marlin under 90 kg (about 231 cm long) and do not recognise landed fish under this weight for contests or trophies. The length distribution of released striped marlin indicates that a high proportion (50%) of tagged fish were over 90 kg.

A total of 223 striped marlin were released in statistical area 048 during the 1997–98 season (Figure 3) compared with 631 in 1996–97 (Davies & Hartill 1998). Many releases were once again made along the east Northland coast, and in the areas around the Three Kings Islands and North Cape, with fewer marlin tagged on the west coast than in the previous season (Figure 4).

The monthly distribution of releases show this to be a summer–autumn fishery with relatively few striped marlin being tagged and released in November and December (Figure 5a). The seasonal pattern of releases is broadly similar to that in previous years (Davies & Hartill 1998, Holdsworth & Saul 1998).

The distribution of tagging effort for striped marlin within the recreational fleet was strongly skewed; as observed in previous seasons, with few vessels responsible for a high proportion of the releases. Five vessels (less than 2% of the participating fleet), tagged and released 25% of the marlin released (Table 3).

During the 1997–98 season, eleven tagged striped marlin were recaptured, which is noticeably more than in any previous season. Prior to this season only 29 striped marlin had been recaptured since tagging started in 1975. Of those recaptured this season, eight were caught by recreational vessels and three by commercial vessels (Tables 4 and 5). Unfortunately, no release information is available for three of the eleven recaptures as the tag number was either missing or not recorded before the marlin was tagged and released for a second time. All of the eight marlin, for which release data were available, were released by recreational fishers. Three of the tagged marlin were recaptured outside New Zealand waters, two by commercial fishers off Queensland, Australia and Fiji and one by a recreational fisher south of Samoa. The marlin recaptured south of Samoa had travelled a net distance of 1642 nautical miles in 167 days. A marlin tagged off the Kaipara Harbour on the west coast was recaptured off Tauranga in the Bay of Plenty 21 days later, and would have travelled a minimum distance of 450 nautical miles via North Cape. The remaining four recaptured marlin moved only small distances and were at liberty for only 9 to 52 days. The first ever reported recapture of a blue marlin was received this season (*see* Table 2), caught by a commercial fisher near Fiji.

Marlin are capable of moving large distances in a short period of time and it appears that they do not remain resident in New Zealand waters for periods greater than a few months (Figure 6a). It appears from short term recaptures that inshore coastal movements occur during the fishing season, with out of season recaptures indicating widespread offshore movements towards the tropics as local waters cool (Figure 7). Striped marlin recaptured in the tropics are usually caught by commercial longliners.

Mako shark

The number of mako sharks tagged this season (501) is less than in the previous four seasons (*see* Table 2). A broad size range of mako sharks was tagged and released, with a mean length of 169 cm (Figure 2b). Almost 61% of all mako sharks released were caught off the east Northland coast (Figure 8), similar to the proportion tagged off this coast in the previous season (Davies & Hartill 1998). Mako were also tagged in low numbers throughout other waters off the North Island and 23 were tagged off Dunedin (Figure 9).

Both the spatial and monthly distribution of monthly releases coincide closely with striped marlin releases (*see* Figures 4, 9 and 5) because mako sharks are taken as a by-catch of the recreational marlin fishery. All Mako tagged this season were released by recreational fishers (*see* Appendix 1). The distribution of tagging effort is relatively uniform throughout the recreational fishing fleet (*see* Table 3).

A total of fifteen mako sharks were recaptured this season, six by recreational fishers and nine by commercial fishers (*see* Tables 4 and 5). Of these, no release information is available for six mako recaptures. Five mako were recaptured outside of New Zealand waters, as far away as the Coral Sea, Fiji and Australia. Over 14%, of all mako recaptures occur in the waters around Fiji (Table 6). The number of recaptures from Fiji has increased considerably in the last two years. Movements of tagged mako in New Zealand waters appear to be localised around east Northland with some movement to the Bay of Plenty and the west coast.

Seasonal movement of mako may be inferred from patterns in the net distance moved by tagged fish relative to their time at liberty (Figure 6b). Tagged mako recaptured near to the point of release (<400 nm), appear to be caught during the same time of year after being at liberty for one or more years; and in one case, as much as 11 years later. However, as mako is a by-catch of the target striped marlin fishery, this pattern is likely to reflect the strong seasonality in fishing effort, rather than seasonality in their availability caused by movement of tagged fish in and out of New Zealand waters. Large movements of tagged mako do occur with recaptures taking place about 1000 nautical miles from the point of release, mostly in the tropics. No clear seasonal pattern in the timing of these recaptures is apparent.

Blue shark

The number of blue sharks tagged has doubled annually since 1995–96, with 724 tagged during the 1997–98 season (*see* Table 2). The size range of tagged blue sharks was broad with the largest individual estimated to be over 4.0 m and some fish in the 60–70 cm length category (Figure 2c). The mean length of blue sharks tagged and released was 146.4 cm.

Over 80% of the blue shark releases were made off the Otago coast (Figure 10). Most of the remaining releases occurred off the east Northland coast (Figure 11). The season was concentrated with over 72% of blue sharks tagged in February (*see* Figure 5c).

Recreational fishers were responsible for over 99% of blue shark releases (*see* Appendix 1). The distribution of tagging effort was strongly skewed, with three boats from Dunedin releasing almost 80% of all blue sharks tagged (*see* Table 3). Fishers from one vessel tagged 288 blue sharks during the 1997–98 season.

Nine blue shark recaptures were made during the season, a record for this programme. Prior to this season only 19 blue sharks had been recaptured since tagging began in 1975. Of the nine blue sharks recaptured, four were caught by recreational fishers and five by commercial fishers (*see* Tables 4 and 5). Of the eight recaptures for which release data is available, two were caught off Australia having travelled 1313 and 1345 nautical miles in 568 and 205 days respectively. There is no clear relationship between net distance moved and time at liberty although several blue sharks have been caught close to the point of release after many months (Figure 6c). The most distant recapture to date has been a blue shark caught off Chile (Table 7).

Kingfish

The number of kingfish tagged has declined over the last four years, with 351 tagged this season compared with 1445 in 1994–95 (*see* Table 2). The kingfish tagged and released this season spanned a wide range of reported lengths, with a mean length of 73.4 cm (Figure 2d).

Kingfish were tagged and released off east Northland, Bay of Plenty, and East Cape (Figure 12). Most releases were made off the Three Kings Islands, Whangaroa Bay, Tutukaka, White Island, and Tolaga Bay (Figure 13), all by recreational fishers (*see* Appendix 1). Two recreational boats were responsible for more than 41% of all kingfish tagged and released (*see* Table 3). Kingfish were tagged throughout the year with effort peaking in February (Figure 5d).

Over the last three years the number of recaptures has declined from 72 in 1995–96, to 48 in 1996–97, to 29 in 1997–98. Of these 29 recaptures, 9 were recaptured by commercial fishers, mostly off east Northland, with three caught between East Cape and the Wairarapa (*see* Table 5). Recaptures by recreational fishers were mostly off east Northland and in the Bay of Plenty (*see* Table 4). The downward trend in the number of kingfish recaptures may be due to a decline in the number of kingfish tagged and released in the last three seasons, particularly near White Island.

Most (86%) of the tagged kingfish recaptures have occurred within the fishing statistical area in which they were released, suggesting that large scale movements are uncommon (Table 8), although a few recaptures have been reported from the Wanganella Bank and Australia in the past. The short distances moved by kingfish recaptured this season (Figure 6d), are consistent with previous results (Davies & Hartill 1998, Holdsworth & Saul 1998).

Kingfish growth

Scatterplots of annual length increment observations from the two data sub-sets are presented in Figures 14a and 14b. High variability in annual length increments was evident in both data sets, with greater scatter in sub-set 2. The large number of negative increments observed in sub-set 2, may be attributed to estimation error by anglers.

Four growth models were fitted to data sub-sets 1 and 2. Models 1 and 2 were fitted to data sub-set 1, and a seasonal growth component was introduced to model 1. Fitted parameter estimates with 95% confidence intervals estimated from 500 simulations are presented in Table 9. The parameter notation is that described by Francis (1988) and is as follows:

g_{50}, g_{100} : mean annual growth increment (cm) at lengths 50 and 100 cm respectively;
u : seasonal parameter related to intensity of seasonal effect;
w : seasonal parameter determining mid-point of growth period;
v : growth variability;
s : measurement error;
p : outlier contamination.

There was a significant improvement ($p = 0.05$) in the goodness of fit of model 1 compared with model 2, however it was not clear whether this was directly related to a real seasonal effect or due to other effects present in the data. The parameter estimates for model 1 were sensitive to the initial start values used in the fitting procedure and did not converge rapidly to a solution. Both models produced similar estimates for expected annual length increments, g_{50} and g_{100} as is illustrated in the similarity in predicted mean growth increments over the length range 50 to 100 cm (Figure 15). Seasonality in annual growth estimated for Model 1 is illustrated in Figures 16a and 16b. The mid-point of the 3.5 month long growth period is in late January. Continuous growth throughout the year is assumed for Model 2 which excludes the estimation of seasonal growth parameters.

Models 3 and 4 were fitted to data sub-set 2. In fitting model 4 to the data, 15 outliers were excluded. Fitted parameter estimates are presented in Table 9. Mean annual growth is very similar to models 1 and 2 (*see* Figures 15, 16a and 16b).

A large component of the total variability in estimated mean annual growth is due to measurement error, particularly for large fish (Figures 17a and 17b). This variability results in negative growth increments being predicted for fish in the larger length intervals, as illustrated for length interval 100 cm. As expected, this large source of variability is increased for models 3 and 4, fitted to data sub-set 2, which derive higher estimates of the measurement error and outlier contamination parameters (*see* Table 9).

Satellite tagging review

The feasibility of using towed satellite tags on striped marlin was tested in New Zealand waters in April and May 1996 by Pete Saul and John Holdsworth from the Ministry of Fisheries in conjunction with Barbara Block from Stanford University. Towed tags are non-archival position locators, which are activated when the fish surfaces. In order for the signal to be detected, an ARGOS satellite must be overhead and the aerial must be out of the water for at least 40 seconds. The tags used were approximately 30 cm long and 10 cm wide with a 40 cm aerial. Tags were anchored to the fish using a 60 cm nylon snood attached to a stainless steel barb. The expected transmitting life of the tags was 6 to 9 months.

Towed tags were deployed on five mature striped marlin which were caught by a recreational charter vessel using standard sport fishing lures. All fish were tagged off the east Northland coast between Cape Brett and the Three Kings. Of the five tags deployed, only one was subsequently detected by satellite. This tag was thought to have become detached from the fish, as it emitted a signal continuously as it drifted slowly in a north-easterly then westerly direction before detection was terminated by the researchers.

Recent tagging programmes have employed two types of technologically advanced tags which show promise. These are: single-point, pop-off satellite tags, and archival tags (Block *et al.* 1998a). Single point, pop-off satellite tags are attached to the fish by a corrosive link which releases the tag from the fish after a period determined by the corrosive properties of the link used. These tags then float to the surface and continuously download logged data by transmitting to overhead ARGOS satellites. Movements of pelagic fish can then be inferred from the positions of these tags and the period elapsed since tagging. As data retrieval is not dependent on fisheries involvement, observations are not influenced by temporal or spatial patterns in fishing effort. Limited hourly temperature data is also logged by these tags. This type of tag was developed by Dr. Paul Howey of Telemetry 2000, of Maryland, USA, in conjunction with researchers from Stanford University. This technology has been used successfully in studies on the movement of blue marlin and bluefin tuna (Block *et al.* 1998b).

Archival tags are microprocessor-controlled, data logging tags that record parameters such as time, ambient light, pressure (hence depth), water temperature and thermal biology. Established nautical algorithms are then used to calculate positions from depth corrected ambient light levels, although latitude estimates are less reliable than longitude estimates (Hill 1994, Klimley *et al.* 1994). These tags are either towed by the animal or surgically implanted, and data can only be retrieved once the animal has been recaptured. As tag return rates for billfish tagged with conventional tags are generally less than 1%, a large number of these expensive tags would have to be deployed to get back a reasonable level of information. This technique has been successfully employed on bluefin tuna (Block *et al.* 1998a; 1998b). Four companies currently producing archival satellite tags are: Norwest Marine Technology (USA), Wildlife computers (USA), Zelcon Inc (Australia) and Lotek (Canada).

Discussion

A total of 2549 gamefish were tagged and released during the 1997–98 season, bringing the total of all fish tagged in the programme to date to 28 829. As in previous seasons, the percentage of marlin caught, tagged and released (62% in 1997–98 compared with 68% in 1996–97and 58% in 1995–96), and the high proportion of tagged fish over 90 kg, indicate a high level of interest and co-operation by anglers in tagging marlin. Less marlin were caught this year, possibly due to reduced fishing effort or local availability, which may have resulted in a decline in the number of marlin tagged. Despite the decline in the numbers of striped marlin tagged this season (880 compared with 1303 in the 1996–97 season), a record number of recaptures were reported. Eleven recaptures were reported this season compared with 29 prior to this season. Increased recapture rates have also been observed for mako and blue sharks. This marked increase may be partially attributed to the introduction of wire reinforced tags last season, which were designed to reduce susceptibility to tag loss or damage and hence improve tag return rates. Of the eleven striped marlin recaptured this season, eight were tagged with reinforced tags of which none were damaged.

The spatial distribution of tagging effort this year was similar to that of the previous season with the exception of the Three Kings / Middlesex Bank area, where there has been a marked decline in striped marlin tagging. Tagged marlin are recaptured after small scale coastal movements, or after larger scale movement to the tropics where they are recaptured by commercial longliners. These patterns are similar to those inferred from recapture data for mako sharks.

As in previous years, there were relatively few billfish and gamefish tagged by commercial fishers, although 39% of tag recaptures in 1997–98 were reported by this sector, which is a useful contribution. Over 38% of the commercial tag returns were from overseas, including the first blue marlin recapture of the programme, which was tagged almost three years ago off Tonga and recaptured over 200 miles away near Fiji. Given the low level of tagging by commercial fishers however, it is not possible a gauge the level of overlap in fishing activity on the marlin populations by the commercial and recreational fishing sectors. The extent of movements of recaptured marlin, mako and blue shark indicate that parts of these stocks may be encountered by both the recreational and commercial fishing fleets operating on the east coast of the North Island and in the tropics.

An estimate of average annual growth of kingfish is presented, which indicates that this is a fast growing species. It was evident from fitting the growth model that measurement error was high. The models fitted to data sub-set 2 did not significantly alter the mean growth estimates, but increased growth variability estimates resulting in a high probability of negative growth being predicted for large kingfish. The high variability in predicted growth may be attributed to fishers estimating length or weight rather than measuring it. In data sub-set 1, where both release and recapture data were measured, lower growth variability estimates were obtained from the model. Closer liaison between fishers and researchers may help to improve the quality of growth increment data.

Although inclusion of seasonal parameters in model 1 resulted in a significantly better fit than that derived from model 2, there was little change in estimates of mean annual growth. The estimated seasonal parameters in model 1 indicate plausible timing for kingfish growth, i.e. during the summer season, when productivity in pelagic species is likely to be high. However, the length and magnitude of this seasonality seems implausible. It is unlikely that no growth would occur for 9 months of the year given the highly productive locations where kingfish were tagged. The slow convergence of the model fit in estimating seasonal parameters may indicate that the intensity and timing of the seasonal growth is unlikely to have been estimated well in model 1. It is possible high levels of measurement error in the data reduced the power of the model to detect real seasonal growth effects. Therefore, model 2 is recommended as being the preferred description of mean annual growth of kingfish.

As could be expected, the parameters in model 2 are similar to those previously calculated using data from the cooperative tagging programme available in 1995 (Holdsworth per. comm.). The difference is that growth variability is higher when model 2 is fitted to this year's data. This may be due to the larger data set used this year. Data from small kingfish (<50cm) are lacking and the availability of more data for these length intervals would improve estimates for g_{50}. Kingfish less than 65cm in length are often not tagged however as they are usually in very poor condition when recaptured (Rick Pollack, pers. comm.).

McGregor (in prep.) provides a review of growth rates estimated for populations of kingfish species found outside of New Zealand waters. To date there are no published estimates of New Zealand kingfish growth rates based on the analysis of skeletal structures such as otoliths or vertebrae. The growth information presented here, based on length increment data does not contain specific information relating to kingfish age and no attempt has been made to present kingfish growth as a function of age. Francis (1988) cautions against making inferences from the length-based growth model parameters to one that describes length as a function of age, such as the commonly used von Bertalanffy growth curve. This would require a more complete model of growth, using both length and age data.

Issues such as release survivorship (Block et al. 1997), movement patterns in relation to environmental variables (Metcalfe and Arnold 1997), stock structure (Restrepo 1996), and spawning area fidelity (Block et al. 1998b) can all be addressed using sophisticated tagging technology. A trial of five towed satellite tags undertaken in April and May 1996 did not however produce any useful results. The failure of this approach should not be regarded as indicative of the utility of satellite tagging technology in general. The fact that one of the tags, which appeared to be drifting, worked continuously until detection was terminated, suggests that satellite tagging will work when the method of deployment and data retrieval is suitable.

As towed tags remain attached to the marlin, their detection by satellite required the fish to remain on the surface for at least two minutes and for there to be an ARGOS satellite overhead at the time. Assuming that the tags were functioning properly, there are two explanations why the tagged marlin were not detected. Either the tagged fish died soon after tagging and sank, thus permanently denying the tag access to overhead satellites, or the tagged marlin do not remain on the surface long enough to be detected. Although the trial sample size is small, it is unlikely that all five marlin would have died soon after tagging as the methods used were identical to those used for conventional tags, and overseas satellite and acoustic tagging studies do not appear to have encountered high initial mortality rates for billfish and tuna. These tags therefore appear unsuitable for tagging striped marlin.

Recent advances in satellite tagging technology have gone away from the towed satellite tag approach. Two methods which are currently being used successfully are pop-off satellite tags and archival tags. Pop-off tags provide an estimate of the net distance travelled since tagging, with. This type of tag could be used to assess initial mortality of billfish released after tagging. Archival tags remain attached to the fish and log parameters such as location, depth and temperature at regular intervals, but the fish must be recaptured as it is currently not possible to retrieve the logged data remotely. Given the rapid advances in satellite tagging technology in recent years, it is possible that a synthesis of pop-off and archival tagging technology may soon become available. Pop-off archival tags would provide good fishery independent return rates combined with information collected on environmental variables encountered by the fish during its time at liberty. This data could then be used to assess movement patterns in relation to environmental variables, enabling cost effective investigation of billfish management issues.

A combination of factors may increase the amount of information on striped marlin movement and distribution relative to fishing effort obtained from this programme. The high levels of striped marlin tagging achieved in recent years will increase the effective tagged population. The new, robust tag will reduce tag damage and loss of release information. The insistence of gamefish clubs that tag release information is provided by their members, has resulted in higher levels of data collection than in cooperative tagging studies in other countries (Peel *et al.* 1996). Anglers who are not members of a gamefishing club will also be encouraged to supply release information on tagged gamefish.

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***Table 1*: Parameters used to derive length from weight measurements**

$$Length = b\sqrt{\frac{weight}{a}}$$

(weight in g, length in cm)

Species	a	b	Measurement method	Source
Striped marlin	0.0134	2.8900	Fork length	Holdsworth (unpub. data)
Blue shark	2.328×10^{-6}	3.294	Standard length	Nakano et al. (1985)
Kingfish	0.0246	2.8463	Fork length	McGregor (in prep.)

$$Length = \frac{\left(b\sqrt{\frac{weight}{a}}\right) - c}{d}$$

(weight in g, length in cm)

Species	a	b	c	d	Source
Mako shark	5.432×10^{-6}	3.1407	-1.7101	0.9286	Kohler *et al.* (1995)

Table 2: **Numbers of fish tagged and released by species and season (1 July to 30 June) for each year of the gamefish tagging programme, and recapture totals as of 30 June 1998**

Season	STM	MAK	BWS	KIN	ALB	BEM	BKM	SWO	YFN	SHA	OSP	Total
1974–75	–	9	1	–	–	–	–	–	–	–	–	10
1975–76	3	17	–	1	–	–	–	–	–	2	–	23
1976–77	2	34	1	1	–	–	–	–	1	–	1	40
1977–78	7	58	–	15	–	–	–	–	–	–	–	80
1978–79	18	152	1	107	1	2	–	–	–	1	4	286
1979–80	17	129	25	22	–	–	–	–	–	3	–	196
1980–81	2	116	7	7	6	–	1	–	–	2	1	142
1981–82	11	185	99	30	14	–	–	–	–	3	3	345
1982–83	6	151	18	56	11	–	–	–	1	4	1	248
1983–84	9	220	15	54	9	–	–	–	5	7	–	319
1984–85	–	97	10	148	–	–	–	–	25	4	1	285
1985–86	2	211	23	323	–	–	–	–	8	1	6	574
1986–87	2	177	12	376	8	–	–	–	7	31	13	626
1987–88	97	505	91	689	40	1	1	6	13	47	44	1 534
1988–89	371	370	122	371	98	1	–	4	63	32	23	1 455
1989–90	366	424	83	427	87	6	4	4	140	30	18	1 589
1990–91	229	419	92	531	40	–	2	5	25	33	24	1 400
1991–92	243	354	128	393	21	5	2	20	39	40	19	1 264
1992–93	387	353	64	694	64	11	1	36	13	24	30	1 677
1993–94	927	667	164	1 100	27	20	2	3	104	19	37	3 070
1994–95	1 206	1 542	176	1 445	5	29	4	10	216	23	60	4 716
1995–96	1 103	1 159	163	641	–	46	6	3	111	30	31	3 293
1996–97	1 303	914	341	407	8	20	5	4	33	36	17	3 088
1997–98	880	501	724	351	1	24	5	–	3	50	10	2 549
Unknown date	4	7	1	6	–	–	–	–	1	–	1	20
Total releases	7 195	8 771	2 361	8 195	440	165	33	95	808	422	344	28 829
Total recaptures	40	216	28	808	–	1	1	–	7	28	15	1 144

Species key

ALB	albacore	KIN	kingfish	SWO	broadbill swordfish
BEM	blue marlin	MAK	mako shark	YFN	yellowfin tuna
BKM	black marlin	SHA	other shark species	OSP	all other species
BWS	blue shark	STM	striped marlin		

Table 3 **: The distribution of the number of tagged fish released by individual boats in decending order and by species with the cumulative percentage (cum %) of total tagged fish by respective boats**

	No. of boats tagging and releasing									
No. fish tagged	Striped marlin		Mako shark		Kingfish		Blue shark		other species	
	n	cum %	n	cum %	n	cum %	n	cum %	n	cum %
288	–	:	–	:	–	:	1	40	–	:
:		:		:		:		:		:
188	–	:	–	:	–	:	1	66	–	:
:		:		:		:		:		:
101	–	:	–	:	–	:	1	80	–	:
:		:		:		:		:		:
96	–	:	–	:	1	28	–	:	–	:
:		:		:		:		:		:
63	1	7	–	:	–	:	–	:	–	:
:		:		:		:		:		:
46	–	:	–	:	1	41	–	:	–	:
:		:		:		:		:		:
43	1	12	–	:	–	:	–	:	–	:
42	1	17	–	:	–	:	–	:	–	:
:		:		:		:		:		:
35	1	21	–	:	1	51	–	:	–	:
34	1	25	–	:	–	:	–	:	–	:
:		:		:		:		:		:
29	1	28	–	:	–	:	–	:	–	:
:		:		:		:		:		:
27	1	31	–	:	–	:	–	:	–	:
:		:		:		:		:		:
19	2	35	1	4	1	56	–	:	–	:
:		:		:		:		:		:
17	1	37	–	:	–	:	–	:	–	:
16	–	:	–	:	–	:	–	:	1	17
:		:		:		:		:		:
14	1	39	–	:	1	61	–	:	–	:
:		:		:		:		:		:
12	–	:	1	6	–	:	–	:	–	:
11	4	44	–	:	–	:	1	81	–	:
10	2	46	1	8	–	:	–	:	–	:
9	1	47	–	:	3	68	1	82	–	:
8	1	48	2	12	1	71	–	:	–	:
7	2	50	1	13	–	:	1	83	1	25
6	5	53	6	20	2	74	2	85	–	:
5	12	60	6	26	2	77	1	86	–	:
4	14	66	9	34	7	85	4	88	1	29
3	25	75	18	45	4	88	5	90	2	36
2	33	82	52	66	6	92	12	93	9	55
1	152	100	168	100	28	100	48	100	41	100
Vessel unknown	4		9		4		–		1	
Total vessels	262		265		58		78		55	

Table 4 : **Numbers of tagged fish recaptured duing the 1997–98 season by recreational fishers by species and statistical area***

	Statistical area																
	002	003	007	008	009	010	012	017	020	024	040	041	042	047	048	999	Total
Striped marlin	1	1	–	–	1	–	–	–	–	–	–	–	–	3	1	1	8
Mako shark	1	2	–	2	–	–	–	–	–	–	–	–	1	–	–	–	6
Kingfish	1	8	1	–	1	6	1	–	–	–	–	–	–	2	–	–	20
Blue shark	–	–	–	–	–	–	–	1	–	2	1	–	–	–	–	–	4
Yellowfin tuna	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1
School shark	–	–	–	–	–	–	–	–	1	–	–	1	–	–	–	–	2
Hapuka	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	1
Total	3	11	1	3	2	6	2	1	1	2	1	1	1	5	1	1	42

* ??? Denotes fish tagged and released but no statistical area given
999 Denotes fish tagged and released outside of statistical areas

Table 5 : **Numbers of tagged fish recaptured duing the 1997–98 season by commercial fishers by species and statistical area***

	Statistical area											
	002	003	008	009	010	011	013	041	045	999	???	Total
Striped marlin	–	1	–	–	–	–	–	–	–	2	–	3
Blue marlin	–	–	–	–	–	–	–	–	–	1	–	1
Mako shark	–	–	1	1	–	–	1	1	–	5	–	9
Kingfish	3	3	–	–	–	1	1	–	1	–	–	9
Blue shark	–	–	1	–	1	–	–	–	–	2	1	5
Total	3	4	2	1	1	1	2	1	1	10	1	27

* ??? Denotes fish tagged and released but no statistical area given
999 Denotes fish tagged and released outside of statistical areas

Table 6 : **Movement of mako sharks as indicated from statistical areas of release and recapture since 1975**

	Recapture area																										
Release area	001	002	003	004	005	008	009	010	011	012	013	014	039	040	041	042	047	048	???	AUS	CAL	FIJ	KER	MAQ	TAS	TON	WAN	Total
002	1	5	3	1	–	1	–	–	1	–	–	–	–	–	–	–	–	–	1	–	1	10	–	–	1	–	–	25
003	1	6	32	1	–	7	5	3	3	1	7	1	1	1	–	1	3	1	2	2	1	10	–	1	1	–	–	91
005	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1
008	–	1	1	–	1	1	2	1	–	1	2	–	–	1	–	–	–	–	–	–	–	5	–	–	–	–	–	16
009	–	–	3	–	–	3	5	1	1	–	1	–	–	–	–	–	–	–	–	–	1	1	–	–	1	1	–	18
010	–	1	–	–	1	–	2	3	–	–	2	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	10
012	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
013	–	–	1	–	–	1	–	1	–	–	–	3	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	7
014	–	–	1	–	–	–	2	1	–	–	3	4	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	11
041	–	1	–	–	–	–	–	–	1	–	–	1	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1	5
042	–	–	–	–	–	–	–	–	–	–	–	–	1	–	1	1	–	–	–	–	–	–	–	–	–	–	–	3
043	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
046	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1
047	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	1
048	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1
Total	2	15	41	2	2	13	16	10	6	2	16	9	2	2	2	3	4	1	3	4	3	27	1	1	3	1	1	192

AUS, Australia; CAL, New Caledonia, FIJ, Fiji; KER, Kermadecs; MAQ, Marquesas Islands; TAS, Tasman sea; TON, Tonga; WAN, Wanganella Bank; ???, area unknown

Table 7 : **Movement of blue sharks as indicated from statistical areas of release and recapture since 1975**

	Recapture area																	
Release area	002	003	008	010	011	012	013	014	017	024	040	043	999	???	AUS	CHL	FIJ	Total
002	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
003	1	2	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	5
009	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
013	–	–	–	1	1	–	2	–	–	–	–	–	1	1	2	–	–	8
014	–	–	–	–	–	–	–	1	–	–	–	–	–	1	–	–	–	2
017	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	1
024	–	–	–	–	–	1	–	–	–	2	–	–	–	–	–	1	–	4
041	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	2
042	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
Total	1	2	1	2	1	1	2	1	1	2	1	1	1	3	3	1	1	25

AUS, Australia; CHL, Chile; FIJ, Fiji; ???, area unknown

Table 8 : **Movement of kingfish as indicated from statistical areas of release and recapture since 1975**

	Recapture area																					
Release area	002	003	005	006	007	008	009	010	011	012	013	014	039	042	043	045	047	048	???	AUS	WAN	Total
002	56	11	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	69
003	6	130	3	1	2	2	–	–	–	–	–	1	–	–	–	–	1	–	4	–	1	151
005	–	3	4	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	8
006	–	1	1	3	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	10
007	–	1	–	5	11	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	17
008	–	1	1	1	–	6	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	10
009	–	2	–	–	–	2	38	6	–	–	–	–	–	–	–	–	–	–	1	2	–	51
010	–	3	2	–	–	3	12	403	2	1	2	–	1	–	–	–	–	–	–	–	–	429
011	–	–	–	–	–	–	–	1	7	1	1	–	–	1	–	–	–	–	–	–	–	11
012	–	–	–	–	–	1	1	–	–	7	2	1	–	–	–	–	–	–	–	–	–	12
013	–	–	–	–	–	–	–	–	–	–	3	1	–	–	–	–	–	–	–	–	–	4
014	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	2
043	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5	–	1	–	–	–	–	6
044	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	2
045	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
047	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	8	–	1	–	–	9
048	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1	–	–	–	3
???	–	–	–	1	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	3
Total	63	152	12	11	18	14	51	412	9	9	9	5	1	1	6	2	11	1	8	2	1	798

AUS, Australia; WAN, Wanganella Bank; ???, area unknown

Table 9 **: GROTAG parameter estimates for 4 growth models fitted to alternative versions of the kingfish tagging length increment data. Upper and lower confidence intervals (U. CI and L. CI respectively) were calculated from 500 simulations. – indicates parameters not fitted**

								Model
						data subset 1		data subset 2
			1			2	3	4
Parameter		U. CI	L. CI		U. CI	L. CI		
g_{50}	10.5	8.8	12.4	11.5	10.1	12.8	12.2	12.0
g_{100}	3.9	3.2	4.6	4.1	3.4	4.7	4.3	4.3
u	2.400	1.500	4.400	–	–	–	–	–
w	0.08	0.01	0.15	–	–	–	–	–
v	0.45	0.24	0.59	0.51	0.32	0.67	0.39	0.37
s	4.500	3.800	5.000	4.600	4.100	5.100	7.000	6.500
p	0.025	0.001	0.066	0.029	0.001	0.073	0.059	0.046

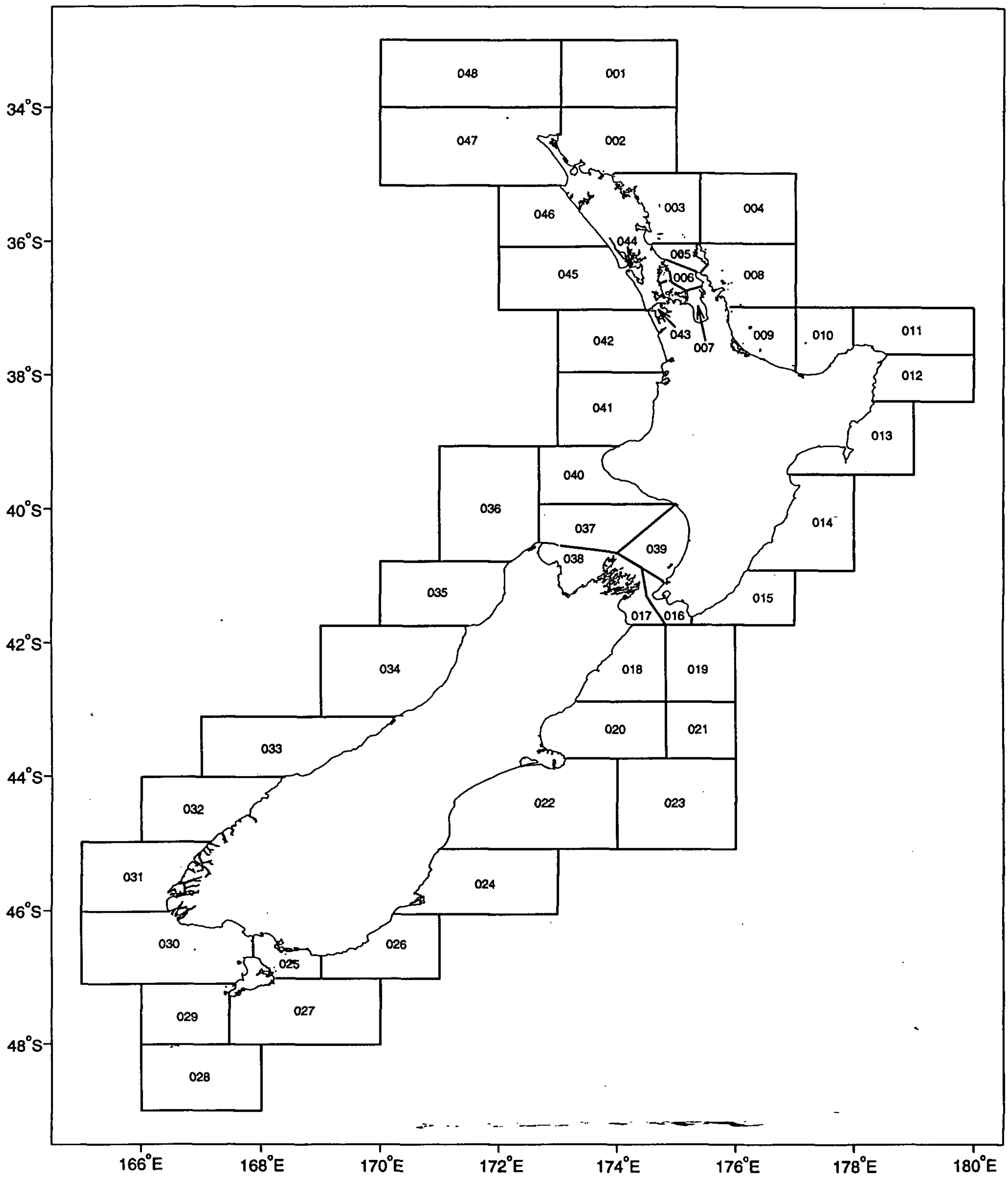


Figure 1: **Commercial fisheries statistical reporting areas.**

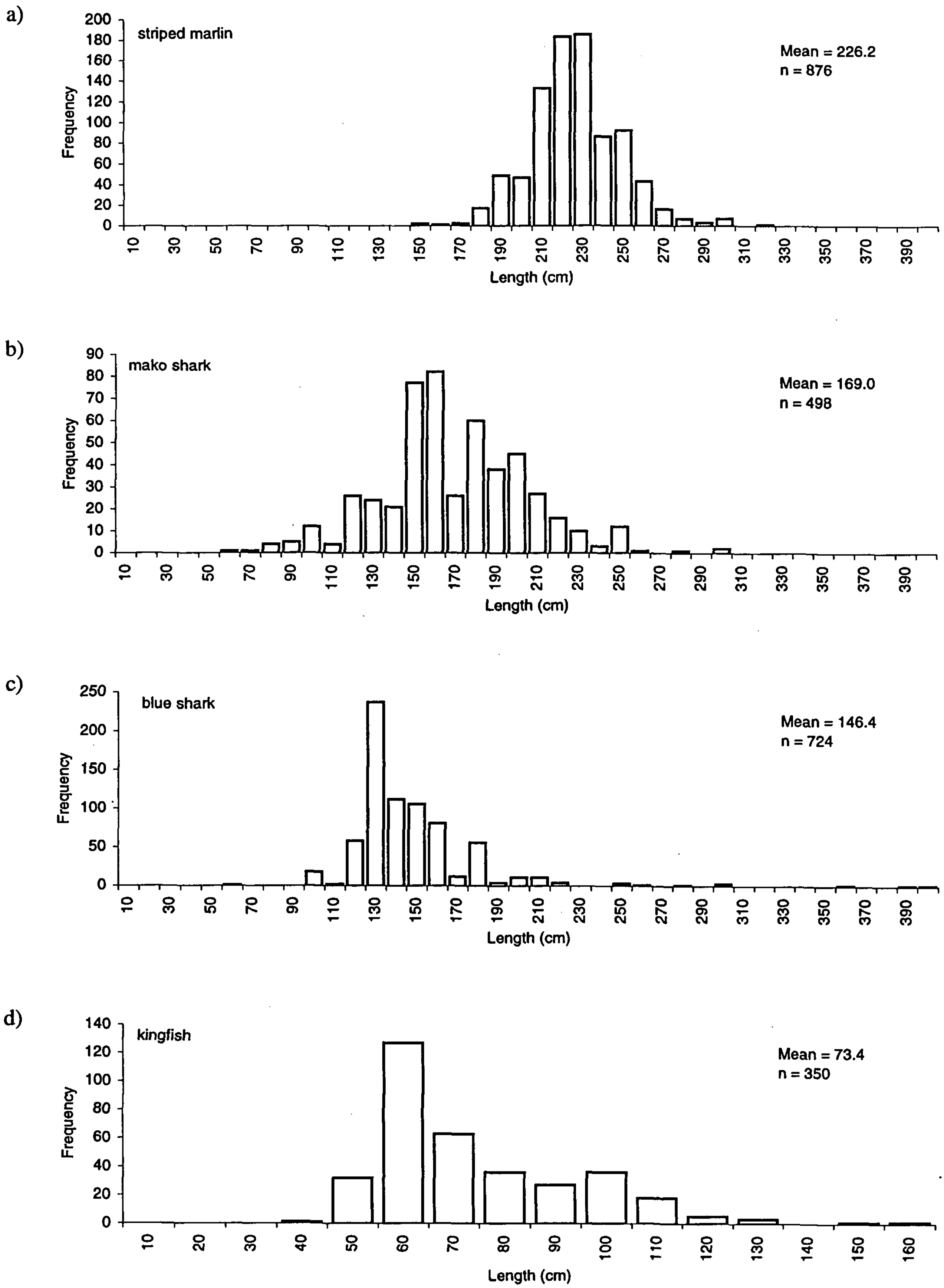


Figure 2 **: Length frequency distribution of a) striped marlin, b) mako shark, c) blue shark, and d) kingfish tagged and released during the 1997–98 season.**

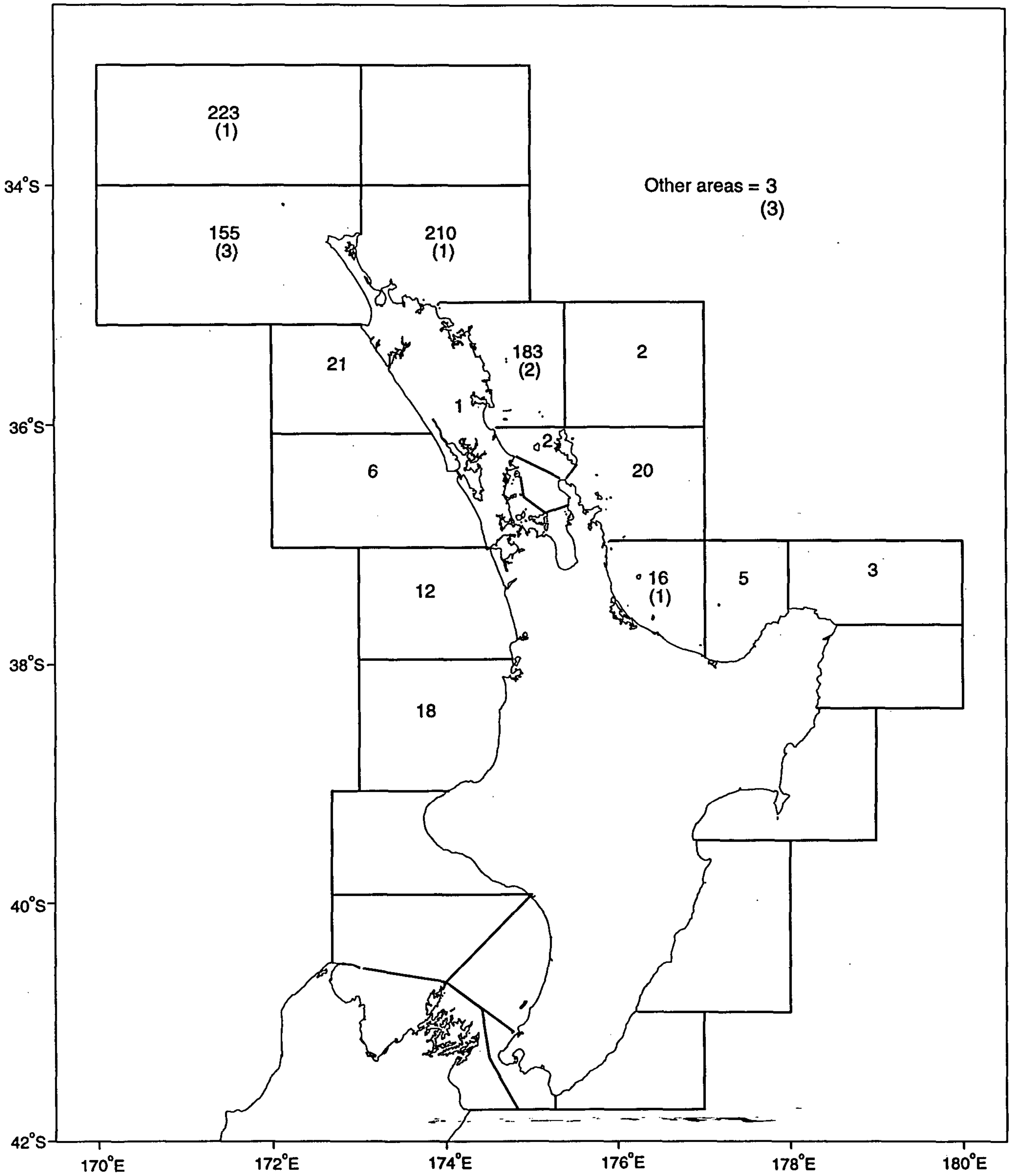


Figure 3: **Numbers of striped marlin released and recaptured (in parentheses) by statistical reporting area during the 1997–98 season.**

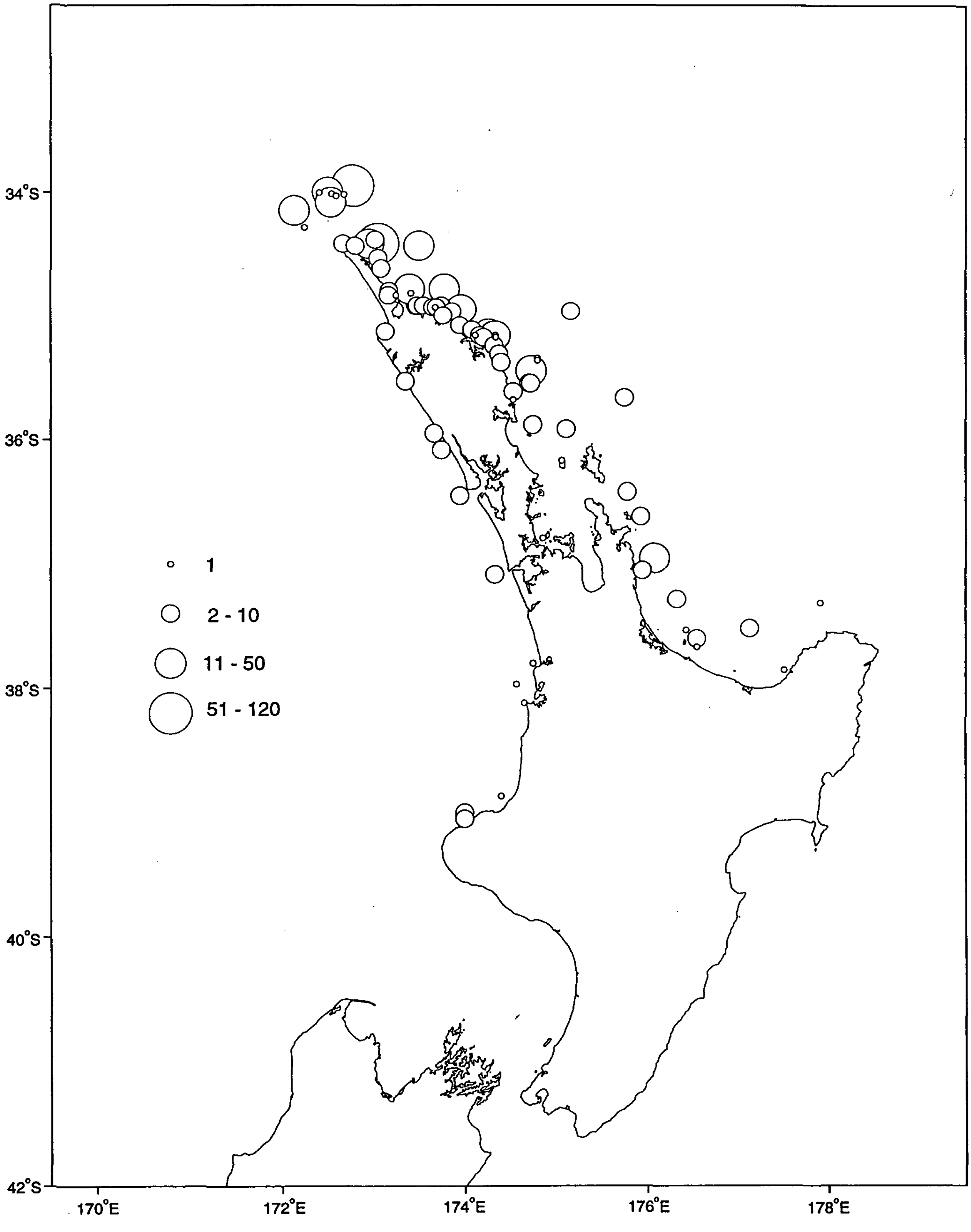


***Figure 4*: Distribution of striped marlin tagged and released during the 1997–98 season.**

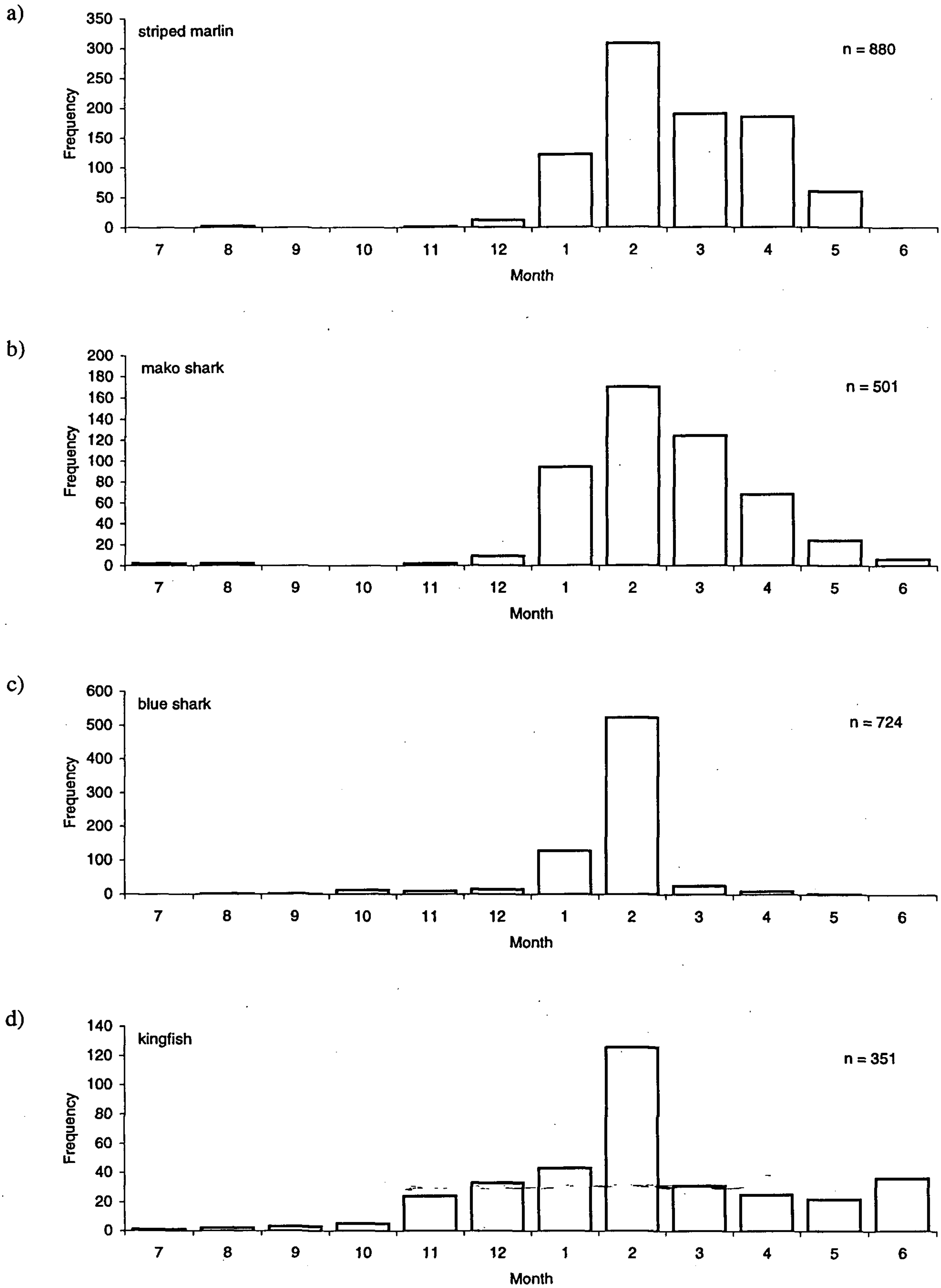


Figure 5 : **Distribution of tagged fish release by month during the 1997–98 season for a) striped marlin, b) mako shark, c) blue shark, and d) kingfish.**

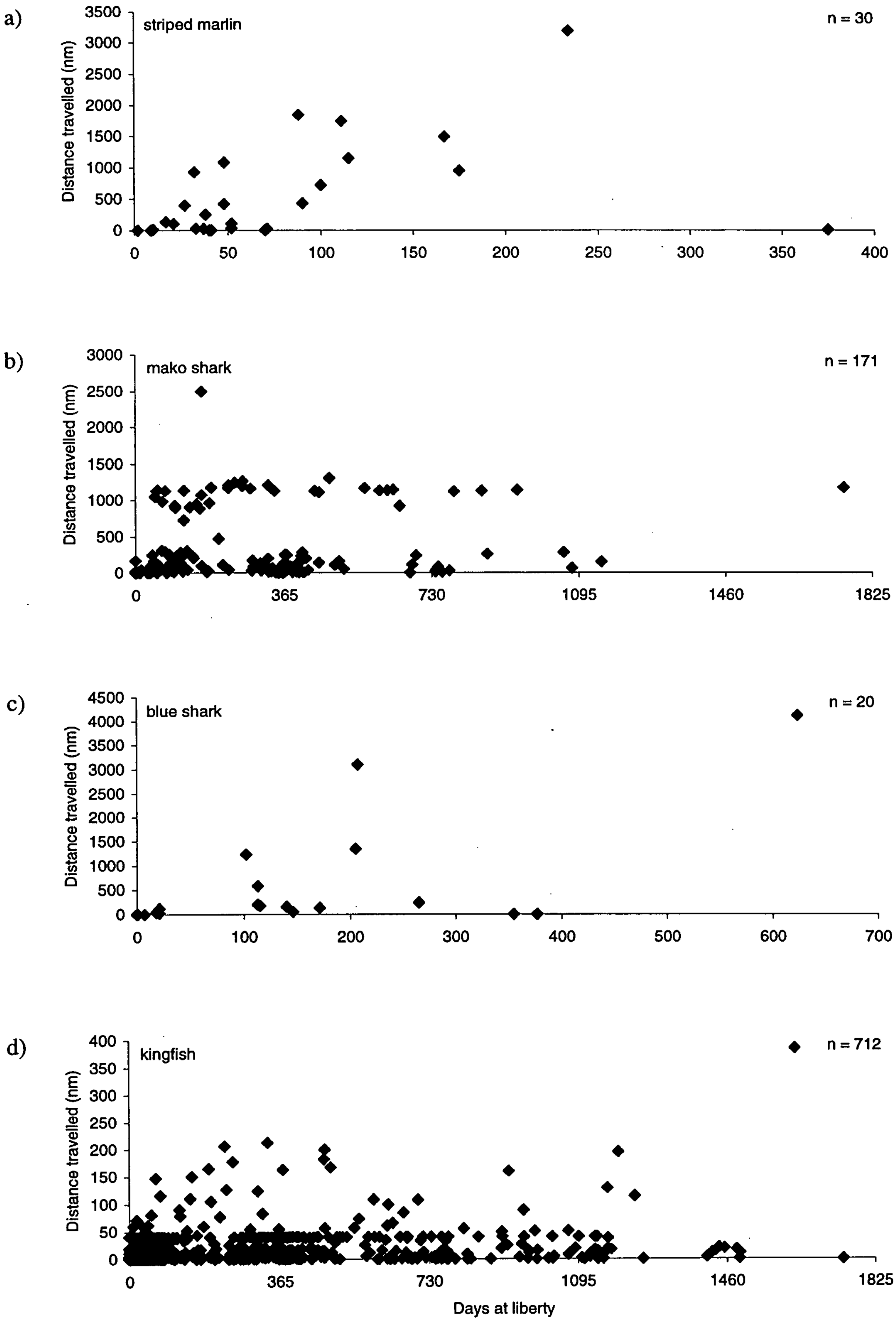


Figure 6 **: Net distance travelled by a) striped marlin, b) mako shark, c) blue shark, and d) kingfish relative to period at liberty.**

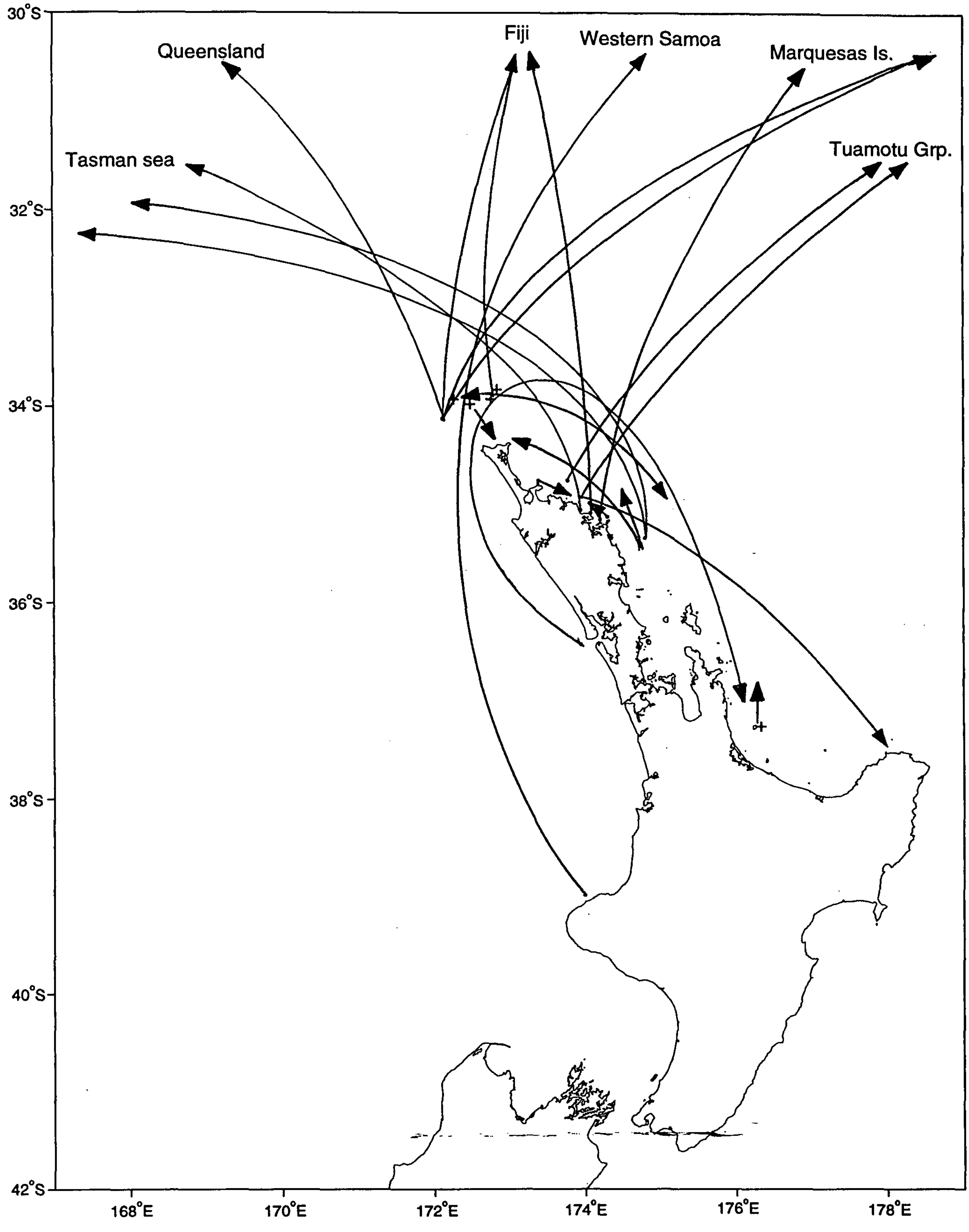


***Figure 7*: Individual movements of tagged striped marlin recaptured by June 1998 (n = 29). Crosses denote no significant movement from release site.**

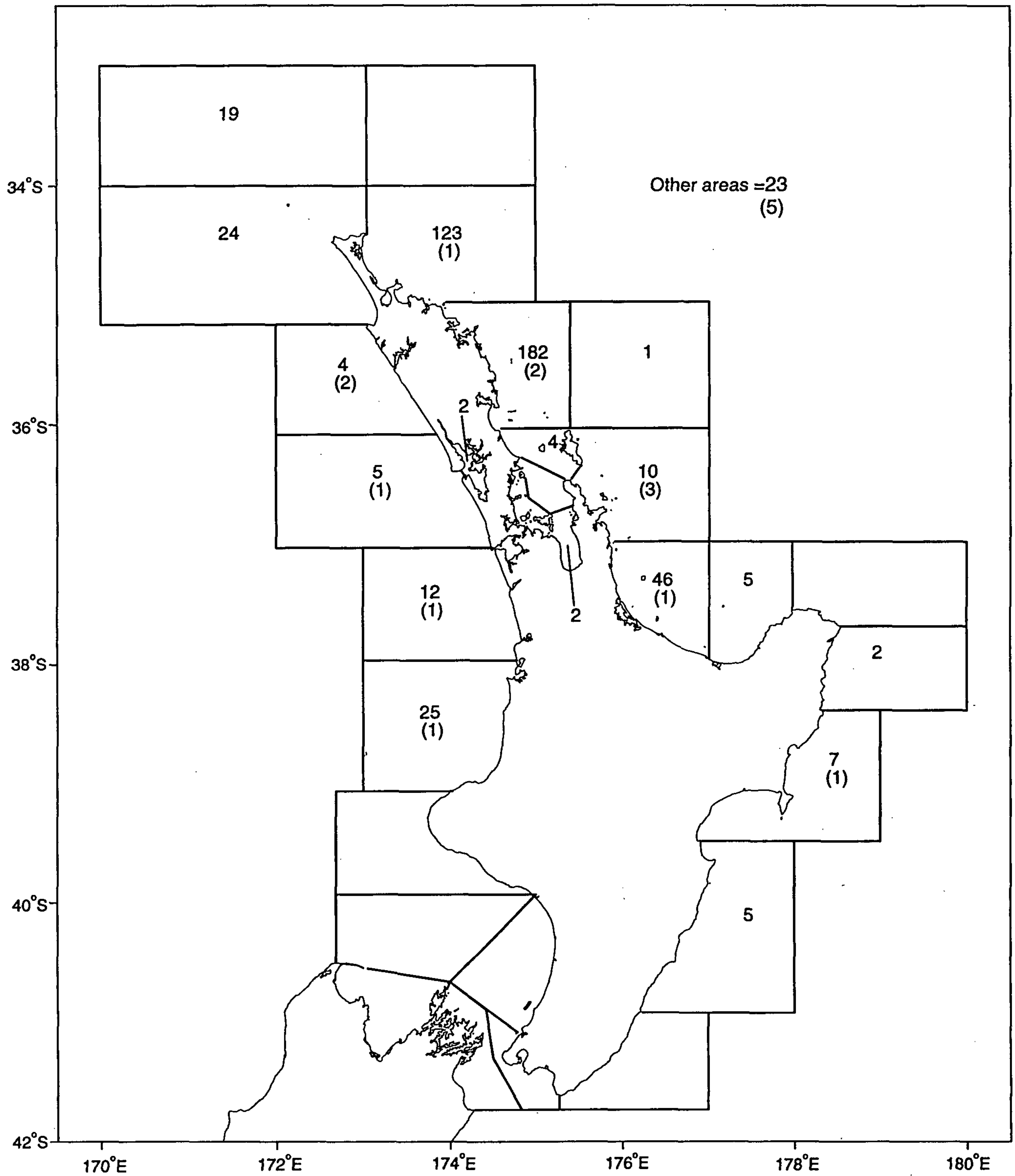


Figure 8: **Numbers of mako sharks released and recaptured (in parentheses) by statistical reporting area during the 1997–98 season. Other areas includes 23 releases from statistical area 024.**

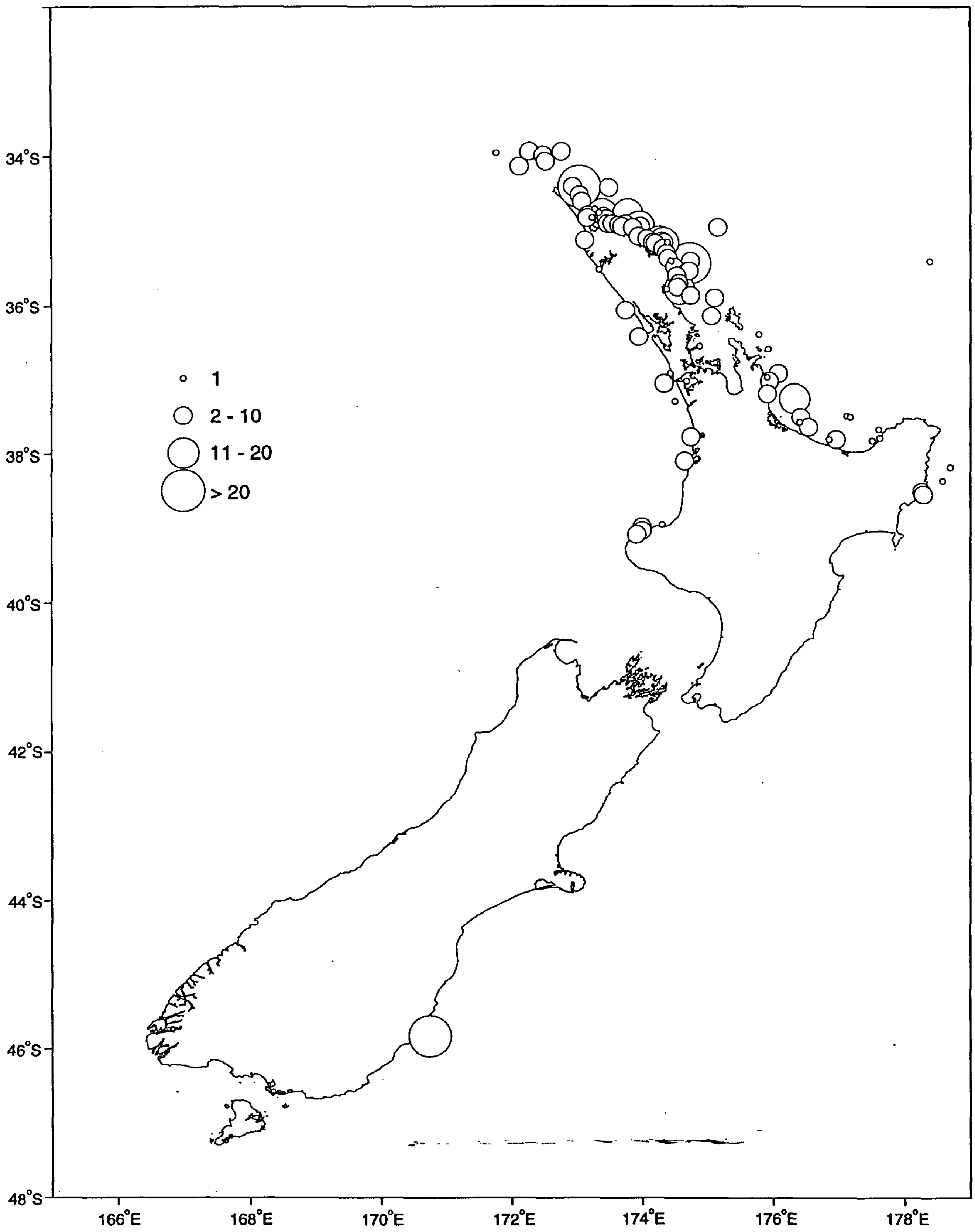


Figure 9: **Distribution of mako sharks tagged and released during the 1997–98 season.**

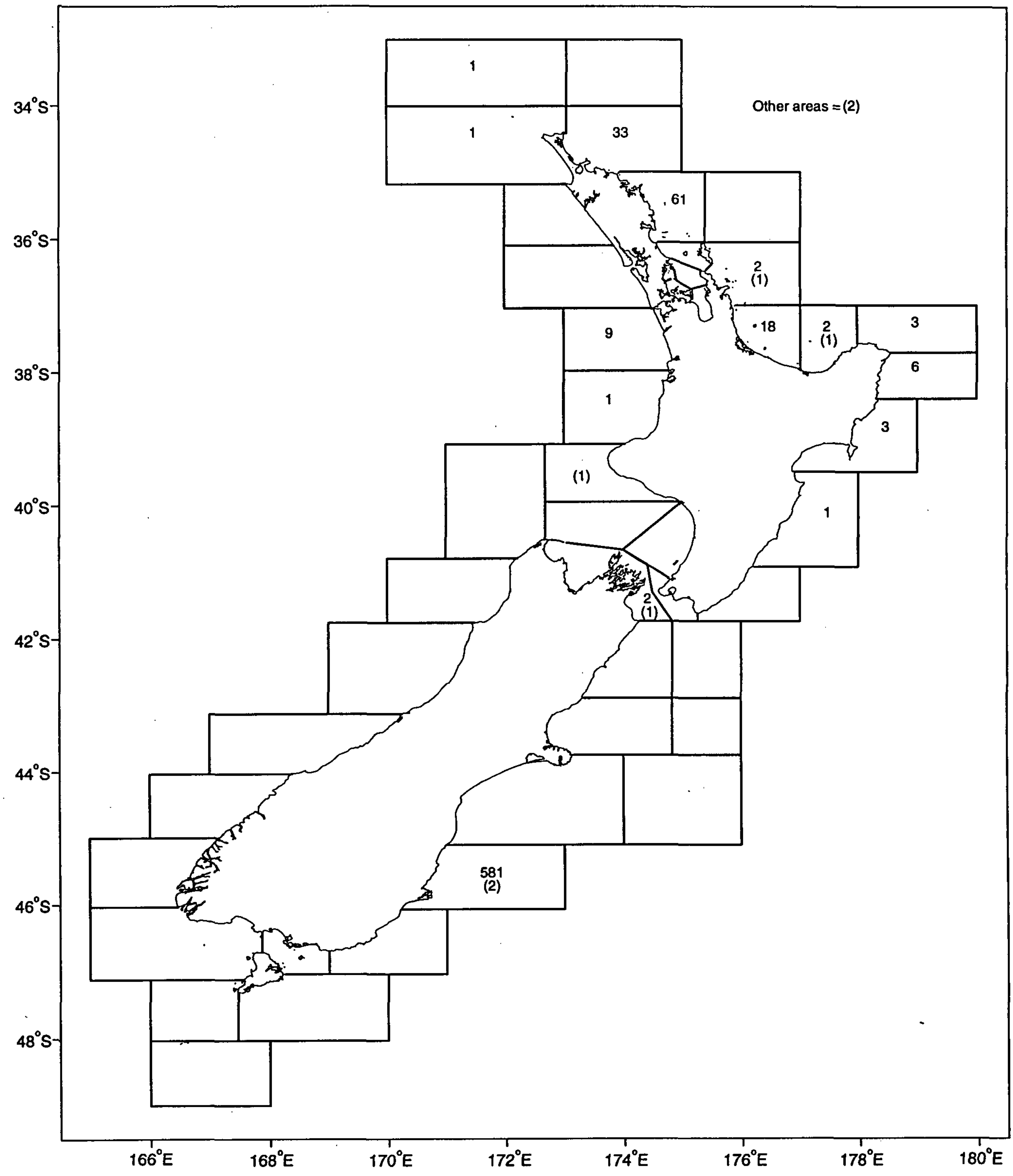


***Figure 10*: Numbers of blue sharks released and recaptured (in parentheses) by statistical reporting area.**

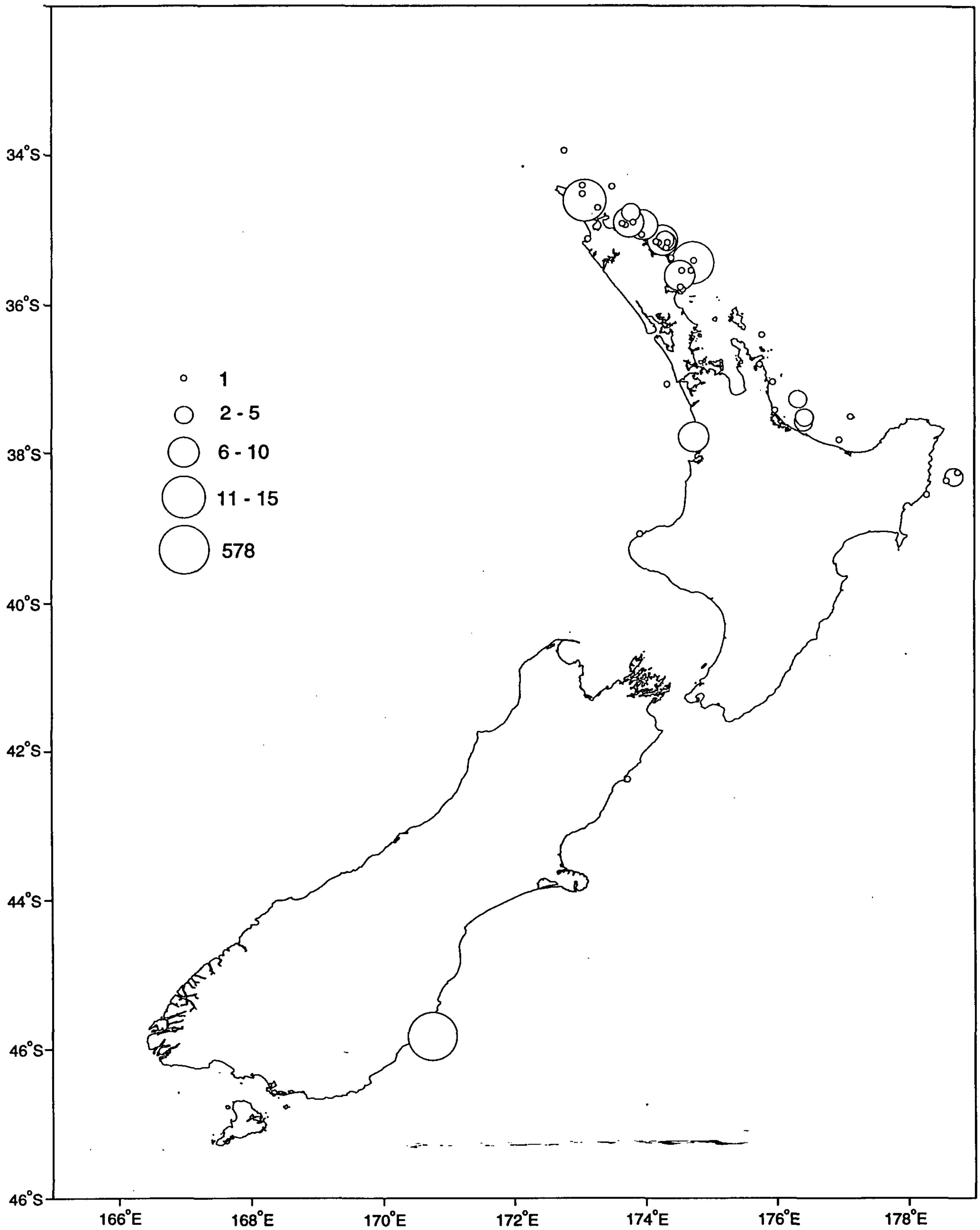


***Figure 11*: Distribution of blue sharks tagged and released during the 1997–98 season.**

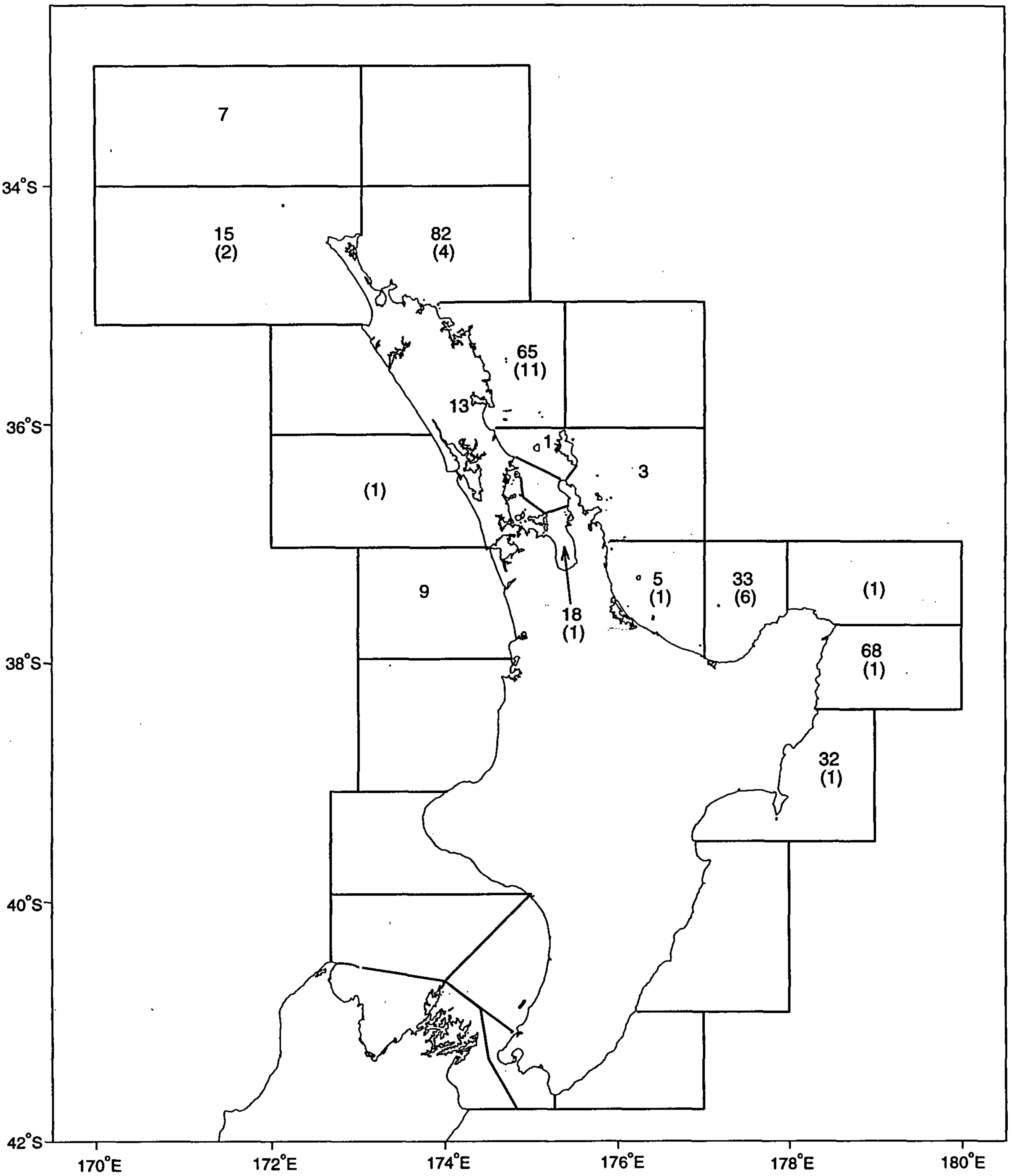


***Figure 12*: Numbers of kingfish released and recaptured (in parentheses) by statistical reporting area during the 1997–98 season.**

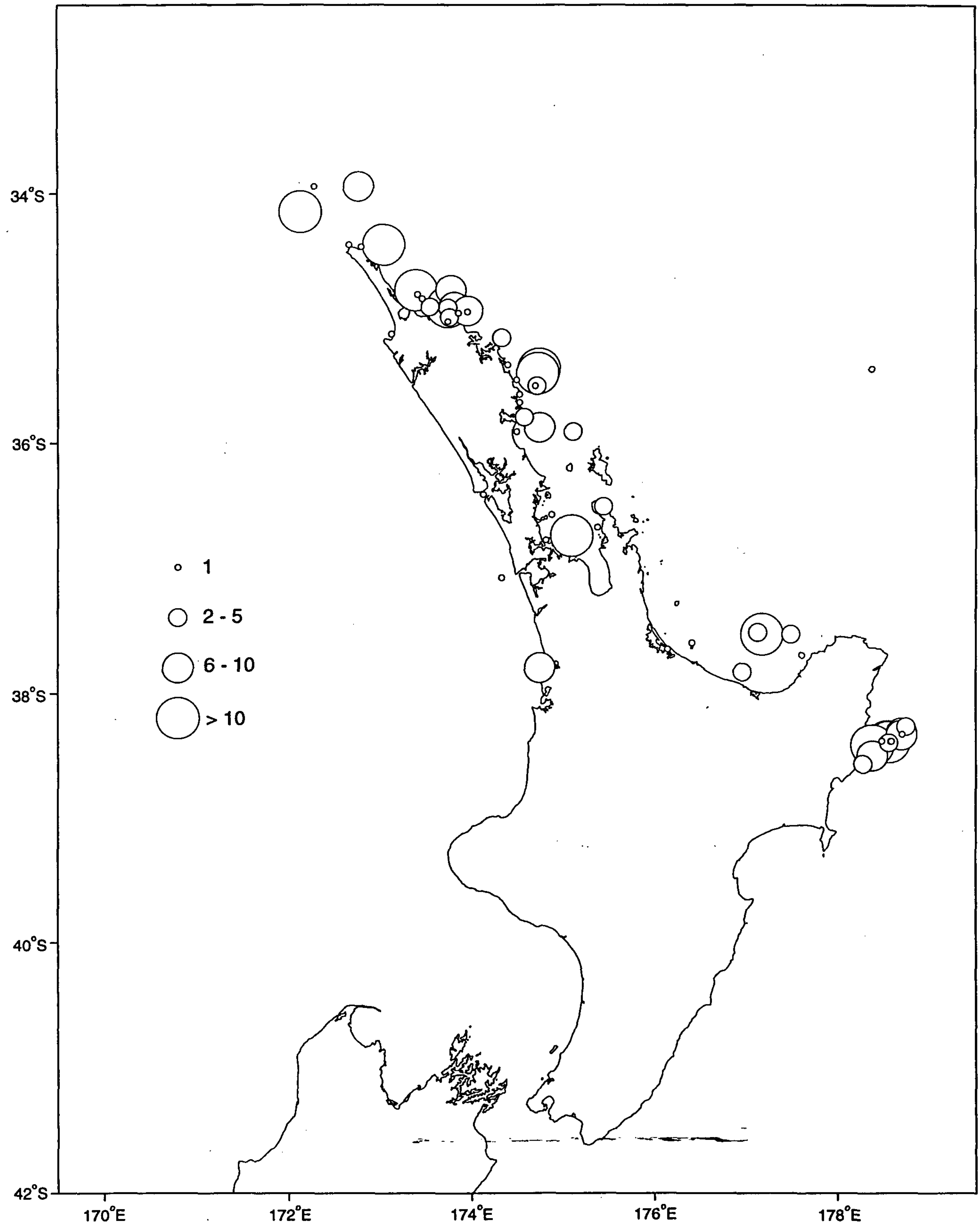
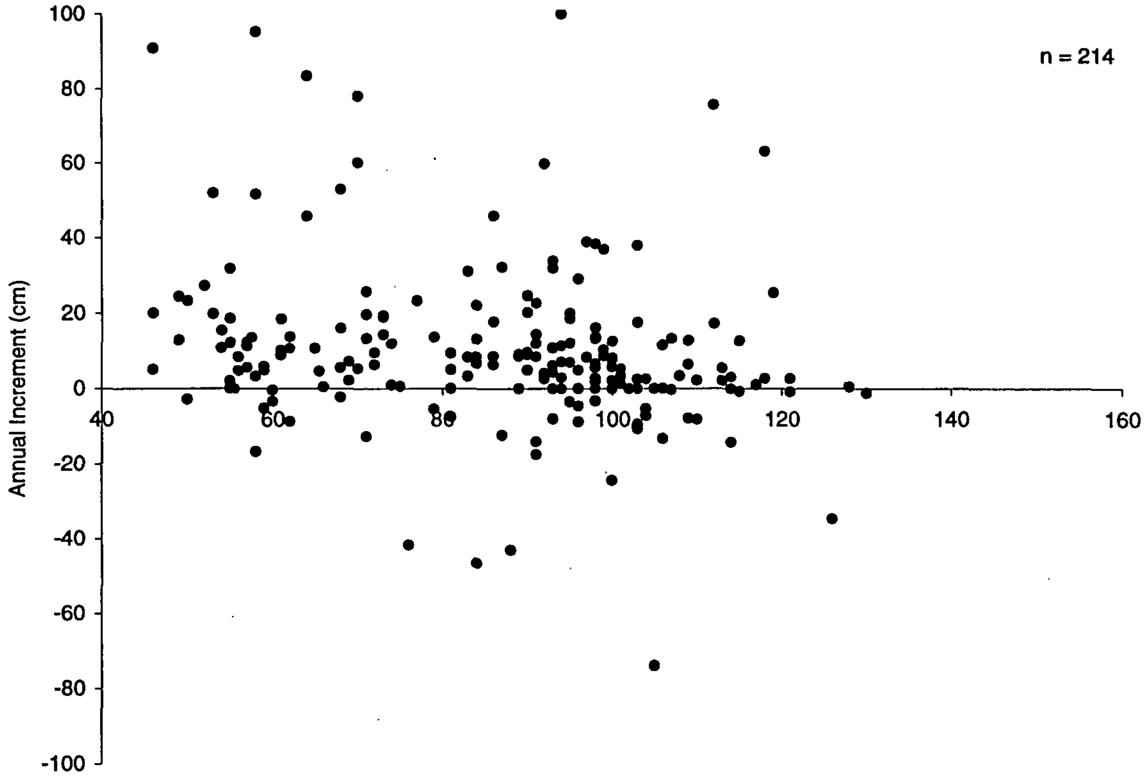


Figure 13: **Distribution of kingfish tagged and released during the 1997–98 season.**

a)



b)

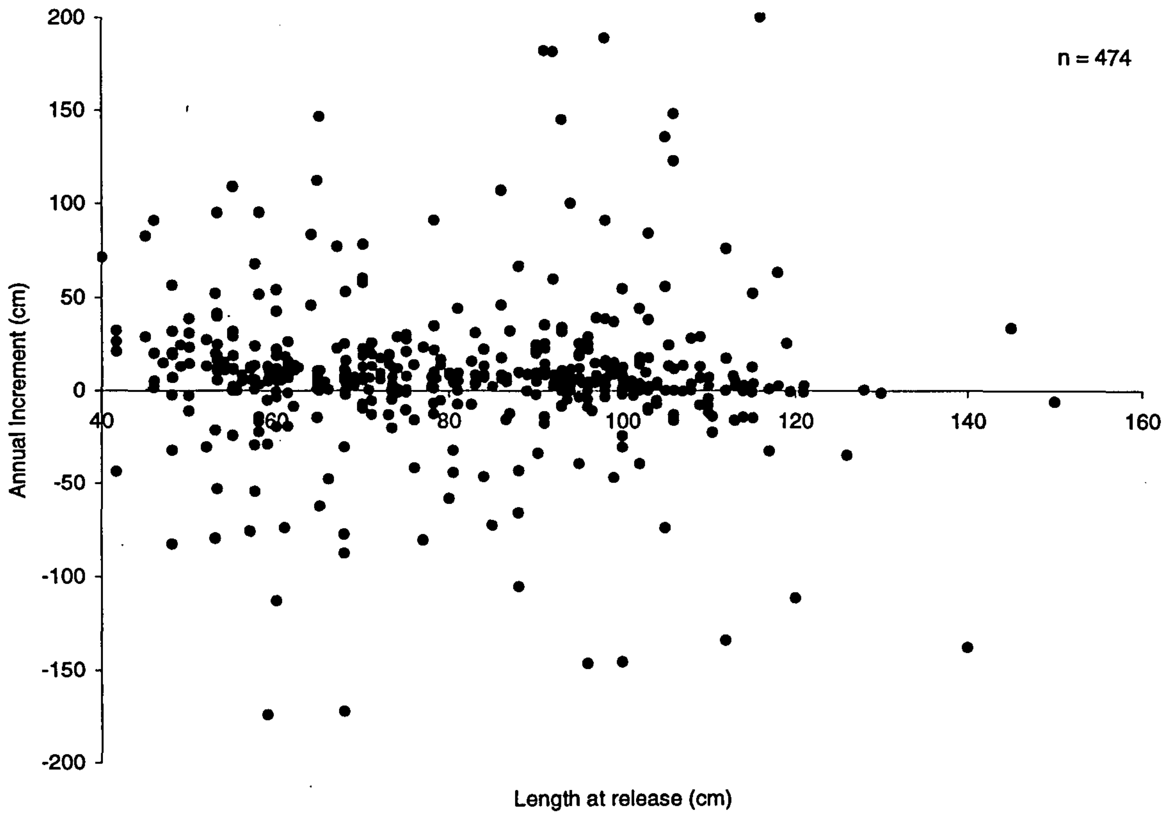


Figure 14 **: Scatterplots of annual length increments of kingfish for a) data sub-set 1 and b) data sub-set 2 (excluding 8 outliers). Note difference in scale for annual increment.**

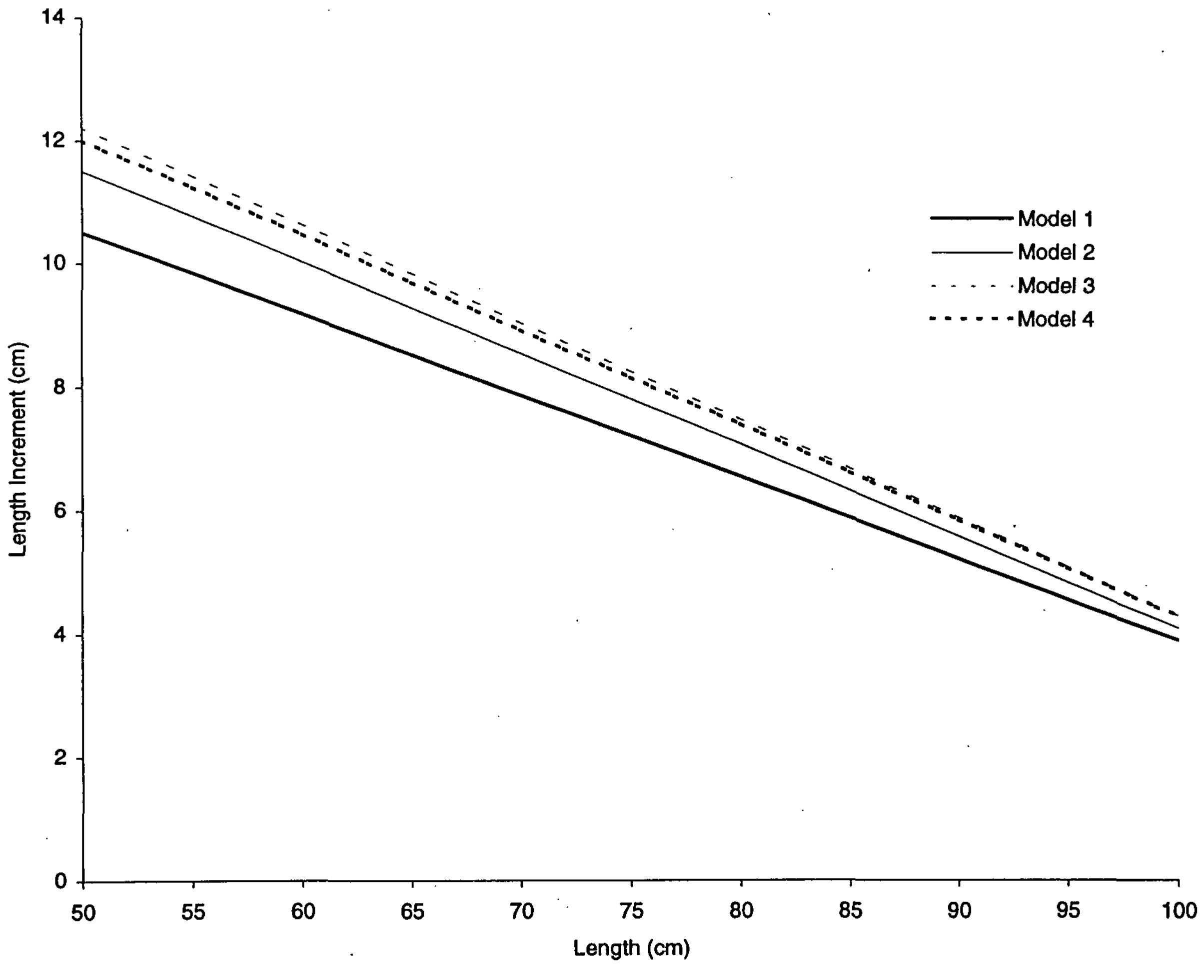


Figure 15 **: Predicted mean and annual length increment for kingfish over the length range 50 to 100 cm for models 1 to 4.**

a)

b)

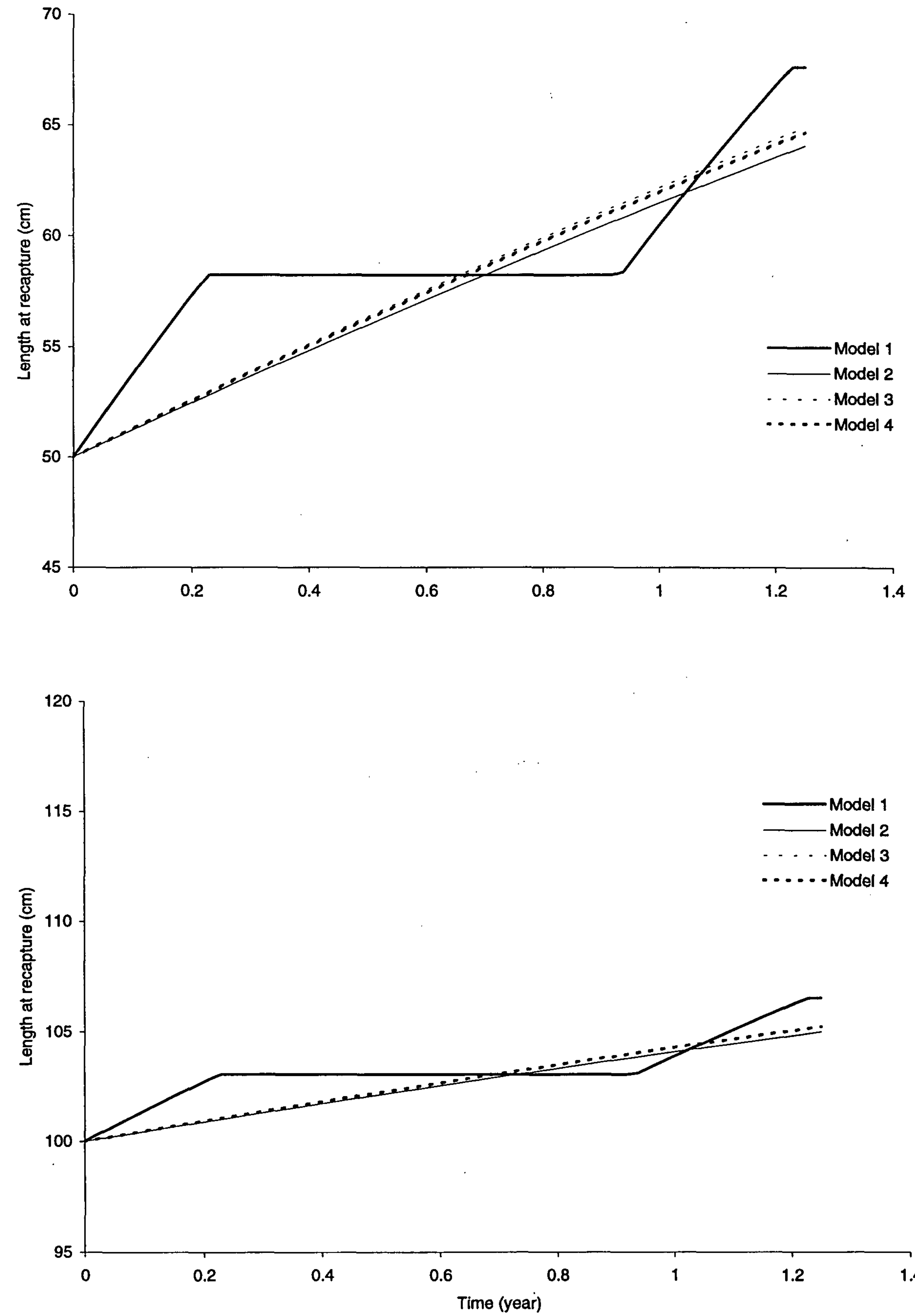


Figure 16 **: Predicted mean increase in length of kingfish with respect to time (year) for a) 50 cm and b) 100 cm release lengths 50, for models 1 to 4.**

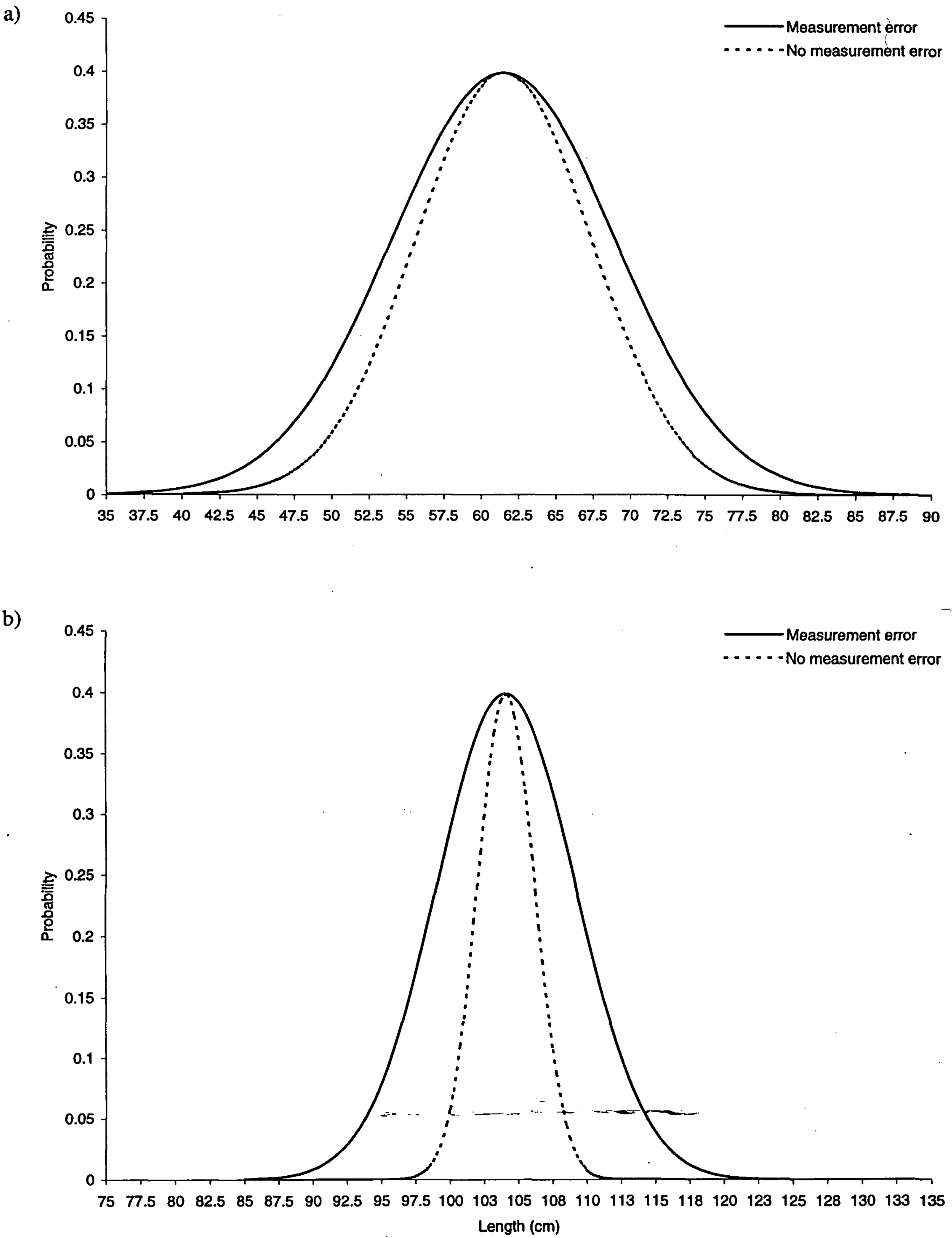


***Figure 17* : A comparison of the distribution of mean annual growth for a) a 50 cm kingfish, and b) a 100 cm kingfish predicted using model 2 with, and without, estimated measurement error.**

Appendix 1 : **Numbers of fish tagged and released by recreational fishers by species and statistical area in the 1997–98 season**

	Statistical area																							
Species	002	003	004	005	006	007	008	009	010	012	013	014	017	024	041	042	043	044	045	046	047	048	999	Total
Striped marlin	210	183	2	2	–	–	20	16	4	–	–	–	–	–	18	12	–	1	6	21	155	223	3	876
Mako shark	123	182	1	4	–	2	10	46	5	2	7	5	–	23	25	12	–	2	5	4	24	19	–	501
Kingfish	82	65	–	1	–	18	3	5	33	68	32	–	–	–	–	9	–	13	–	–	15	7	–	351
Blue shark	33	61	–	–	–	–	2	18	2	6	3	1	2	581	1	9	–	–	–	–	1	1	–	721
Other shark species	1	13	–	–	1	5	–	3	2	1	–	1	–	10	1	5	3	1	–	–	2	1	–	50
Other species	2	3	–	–	–	–	1	1	3	–	–	–	–	–	–	–	–	1	–	–	3	4	24	42
Total	451	507	3	7	1	25	36	89	49	77	42	7	2	614	45	47	3	18	11	25	200	255	27	2 541

999 Denotes fish tagged and released outside of statistical areas

Appendix 2 : **Numbers of fish tagged and released by commercial fishers by species and statistical area in the 1997–98 season**

	Statistical area		
Species	010	011	Total
Striped marlin	1	3	4
Blue shark	–	3	3
Other species	–	1	1
Total	1	7	8