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S.J. Parker
L.J. Paul
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S.J. Parker
L.J. Paul
M.P. Francis

NIWA
Private Bag 14901
Wellington 6241

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EXECUTIVE SUMMARY

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This project used existing opportunistic collections of häpuku (HAP) otoliths to search for large changes in regional population age structure since the early 1990s through differences in length at age (growth rate), or through differences in the relative abundance of younger or older age classes. This project is the first attempt at ageing large numbers of häpuku otoliths from a catch sampling perspective, compared to a focused ageing-technique validation study. The results of the analysis are used to propose a design for a catch sampling programme for häpuku (and perhaps bass (BAS)).

Häpuku otoliths have been collected in an opportunistic manner by the Ministry of Fisheries Observer Programme since 1993. Some earlier samples from small research projects were collected in the 1970s and 1980s (Johnston 1983). Sufficient samples exist to define three main regions for comparison: Southern (Southland), Western (west coast of South Island and Taranaki Bight), and Northeastern (east coast North Island). An early-versus-late Southern comparison was made between samples collected in 1993–1996 and 2005–2007. In addition, a comparison of year class strength was made for the period 1998−1999 between the Northeastern, Southern, and Taranaki Bight samples, focusing on smaller (recruiting) fish. All existing samples collected from the Kermadec region were aged as these samples provide the only information available on a lightly fished population of häpuku.

Results of age structure comparisons showed that the oldest fish and the highest proportion of observed adult (greater than 75 cm long) females older than 10 years old were found in the Kermadec region (57%). Although these were line-caught fish, this was similar to the proportion greater than 10 years old (38%) for trawl-caught fish in the Northeastern region (Quota Management Area (QMA) 2). The proportion greater than 10 years old in the Southern region in the early 1990s was 13%, dropping to 6% in 2005-2007.

Most small fish (less than 65 cm long) from a single year were 3–4 years old, but the number of age classes present was so few that a meaningful comparison of proportion at age among regions was not possible.

The age data developed in this project added significant samples and new spatial coverage to the age, growth, and maturity data of Francis et al. (1999) and new parameter values are provided. No regional differences in growth, spawning season, or age at maturity were detectable.

The fisheries in each QMA were characterised to provide the background necessary to design a catch sampling programme, and an initial design for a sampling programme for HPB 1 was developed as a template. Strata to incorporate in the sampling plan are somewhat different among QMAs, but all have the constraint that individual landings typically consist of few fish, and these are spread over many small vessels, over most months, among varying ports each year, and with an unknown mix of häpuku and bass. Data from an initial catch sampling programme in HPB 1 would be valuable for generating a robust statistical design for other QMAs. Although potential exists for a cooperative sampling programme with industry to avoid the use of observers, the level of participation would need to be very high and there would be costs to vessel crews in collecting and tracking metadata for collected fish.

1. INTRODUCTION

Little information exists on the population structure, age structure, or age at maturity of häpuku (*Polyprion oxygeneios*) or bass (*P. americanus*). A methodology to age häpuku has been developed and validated using otolith thin sections (Francis et al. 1999), but no large-scale ageing studies have been completed.

Häpuku have been sampled for total length, weight, otoliths, and maturity status opportunistically since the late 1970s (first as part of research projects and then through the Ministry of Fisheries Observer Programme), resulting in more than 5800 otolith pairs in storage. However, the numbers sampled in each Quota Management Area, each year, and from different fisheries were *ad hoc* and sporadic (Table 1). Most otolith samples have been taken from häpuku caught as bycatch on larger fishing vessels, usually in trawl fisheries. In contrast, target häpuku fisheries are usually worked by small fishing vessels, and the catch is often processed (headed and gutted) at sea, making data and otolith collection difficult. Consequently, even broad temporal and/or spatial comparisons of age structure, although theoretically possible, have not been considered feasible.

The objectives of this project were to a) determine whether existing otolith collections could provide useful information about age structure differences among regions, b) demonstrate that production ageing is feasible, and c) scope a commercial catch sampling programme to collect more appropriate age structure information on häpuku (and perhaps bass) in the future.

The report first examines existing otolith samples to compare historical indices of age structure. It then updates available biological data with new age information, and then develops a template for a catch sampling programme by characterising the fisheries, determining appropriate sampling strata, and recommending an approach to collecting catch-at-age information for häpuku.

2. EXISTING OTOLITH SAMPLES

2.1 Samples available and aggregation rationale

A summary of samples available from all sources shows 5867 otolith pairs from 12 areas beginning in 1979 (Table 1). Samples in early years were based on research collections, were not sampled as part of an age sampling programme, and consisted of relatively low numbers of fish. Hence, developing an age structure for any area prior to 1993 is not feasible. Table 1 includes samples from research collections from the *trawl* research database, and all observer samples from the *COD* database. Of the 5867 samples identified, 5605 were from the Observer Programme, and 262 were from research surveys or other special research collections. Observer Programme collections were dominated by Southland samples primarily from bycatch in the squid trawl fishery.

Two analyses were conducted with existing otoliths. Samples were culled and aggregated to generate regionally distinct groups of otoliths with the goal of comparing the proportion of older fish among regions or between early and recent periods, or to examine the age structure of newly recruiting fish to determine whether the recruitment signal varied regionally.

2.1.1 Fishery selectivity

Six main gear types typically catch häpuku: bottom trawl, midwater trawl, bottom longline, vertical drop (or Dahn) line, trotline, and set net (Table 2). Analysis of otoliths from set net and trotline fisheries are not considered further due to lack of samples, although a locally important set net fishery exists seasonally off Kaikoura and is considered below in “Catch Sampling Plan”. The length distributions of sampled fish show that the average size of häpuku is smaller in trawl fisheries than in line fisheries (Figure 1). However, the size distributions from midwater trawl and bottom trawl are nearly identical, and the distinction between bottom and midwater trawling relative to häpuku catch − especially distance of gear from seafloor − is not clear-cut, so these samples were pooled as “Trawl” for analysis.

The two line gear types also show similar size distributions, but Drop lines tend to catch more large fish than bottom longlines, regardless of region fished. This is likely to be due to the tendency to fish droplines relatively close to seafloor structures such as reefs and ledges where larger fish are found (Paul 2002a, b). However, the sample sizes from line fisheries were too small to provide spatial or temporal subgroups, leaving trawl-based samples as the only viable source for otoliths for comparison (Table 2). Kermadec samples from line gear were included in this project because they were the only samples available from a lightly fished region and may provide information on growth and maximum age.

Häpuku bycatch in any of these observed fisheries was rare, so in more than 90% of the cases, only one fish was observed per fishing event; and only one or two fish were observed in 99% of the fishing events. This matched the pattern observed in the landed catch (see characterisation below). Samples were assumed to be randomly selected from the catch, therefore it was not necessary to scale the numbers observed at age to the total catch for these comparisons.

2.1.2 Season

Samples of häpuku were predominantly from the squid trawl fishery, which occurs mainly during summer months (Figure 2). Catch by other gear types and in other areas was spread more evenly throughout the year (see below), although fewer fish were sampled during the winter/spring spawning season. If there were significant seasonal movements there may be some confounding effect from sampling in different seasons, but without further information on migration dynamics this cannot be addressed.

2.1.3 Spatial distribution of study areas

Based on studies of häpuku distribution from tagging and fishery catch descriptions (Beentjes & Francis 1999, Francis et al. 1999, Paul 2002a, b, c), samples from several areas were aggregated into larger regions to increase sample sizes for comparisons.

Some areas were omitted because of potential population mixing, or very low sample sizes. Cook Strait is likely to contain migratory fish from other regions as well as residents, particularly just prior to the spawning period when the main targeted fishery occurs (Paul 2002b). The Cook Strait groper fishery is also difficult to characterise because catches and landings are reported under four different Fishstocks which share boundaries there. Therefore, samples from this region were excluded as they could be from mixed populations and not indicative of a Cook Strait “stock.”

Based on the total numbers of samples available and the geographic location of those samples, several QMAs were merged into larger regions for analysis (Figure 3). Samples from QMAs 7 and 8 (Challenger (CHA) and Central Egmont (CEW)) were merged to create a *Western* region. QMAs 5 and 6 (Southland (SOU), Sub-Antarctic (SUB) and SOI (Southern Islands)) were combined into a *Southern* region. Auckland East (QMA 1) and Auckland West (QMA 9) formed a *Northern* region. However, this region was low in total sample size (only 100 combined), and it is not known whether eastern and western fish are distinct in some way, therefore, these northern samples were excluded from further study. The *Northeastern* region (east coast North Island, QMA 2) borders on Cook Strait, but there was good spatial separation of samples from other regions, and an adequate sample size. QMA 2 samples from Palliser Bay were excluded from QMA 2 due to their proximity to Cook Strait. The large *East Coast South Island* (ECSI, QMA 3) and *Chatham Rise* (QMA 4) regions are likely to contain mixed populations of fish from either side of the Subtropical Convergence, are spatially intermediate to other defined regions, and were not included in the regional analysis to minimize and simplify the number of comparisons. We note that other biological information from the ECSI area is incorporated in biological analyses below as appropriate. There are a significant number of otolith samples from these two important regions, which could be used in subsequent studies (Table 2). Samples from the Kermadec region (QMA 10) were included in the analysis because the region has experienced the lightest fishing pressure of all (see below) and represents a near natural population.

The result of the aggregation was three regions that are spatially isolated: Southern, Western, and Northeastern (Figure 3). The Southern samples were generally taken from the squid trawl fishery near the southern Stewart–Snares Shelf, the Western samples from Taranaki Bight, and the Northeastern samples from the east coast of the North Island.

2.1.4 Size and sex selection

Different levels of age truncation in different regions may provide evidence of an exploitation signal. However, samples required to compare the full selected age compositions of each region or time were not available. Therefore, as an index of regional differences in the relative abundance of older fish, the metric chosen was the proportion of females older than 10 years. This metric is arbitrary, but a large difference in the proportion of adult fish that are more than 10 years old could be an indication of age truncation through time, or be a consequence of different population dynamics in different regions. Age 10 was chosen because the total sample age distribution showed a low proportion of fish older than this; a higher cut-off age would give more spurious results.

Overall, the sex ratio of the sampled catch was about 1:1. However, adult males tend to be somewhat smaller than females and the sex ratio becomes dominated by females as the fish grow, becoming especially pronounced for fish greater than 100 cm in length (Figure 4). Therefore, for examination of age truncation in a given region, in order to maintain adequate sample sizes, otolith samples analysed were restricted to trawl-caught female fish larger than 75 cm. The size of 75 cm was chosen because it is the approximate length at maturity estimated by Francis et al. (1999), and therefore provides a biological basis for examining the adult portion of the population. Only 25% of the otolith samples are from fish greater than 75 cm, and only 3% from fish greater than 100 cm. No discernable bias was observed in the size of fish sampled for otoliths compared to the distribution of all fish measured within the trawl fisheries (Figure 5).

To compare the proportion of older fish between regions or years, the proportion of younger fish in the analysis would need to be stable (i.e., no strong year class should be present that artificially inflates or deflates the proportion of older fish present). By including only fish 75 cm or larger in the analysis, most fish younger than about 8 years old (i.e., age at maturity) would be excluded. Year class variation will have been dampened by age 8. In addition, to obtain the sample sizes required, samples were pooled over a 3–4 year period. These pools would tend to ‘average out’ and stabilise the proportion at age and the proportion of “young” fish.

The second task was to examine year class variability for evidence of differences in timing of recruitment pulses between regions. For this objective, younger fish were used. Samples were limited to fish smaller than 65 cm (juveniles) from trawl collections. In order to maximize sample size, and because males and females grow at the same rate until maturity (Francis et al. 1999), this comparison combined the sexes.

A total of 152 fish sampled from the Kermadec region from 1993−1999 provided a good range of ages for that region, and provided some baseline information on maximum age and age structure of a lightly exploited population. However, these fish were not captured by trawl gear and cannot be directly compared with the age structures from other regions based on fish taken by trawl gear.

The sample sizes within a single year were too small to make comparisons between regions or through time (Tables 3 & 4). Otoliths were selected as described by Parker and Paul (2008), essentially identifying groups of years and regions to compare in time and space while attempting to generate sample sizes of more than 50 individuals. This resulted in seven groups with a total of 647 otoliths (Table 5).

2.2 Production ageing

An otolith from each selected fish was prepared and aged following Francis et al. (1999). In summary, thin sections (500 µm) were viewed with transmitted light, and the dark annuli or growth zones were counted. All otolith sections were evaluated by a single reader, with a random subset of 100 otoliths also evaluated by a second reader. The index of average percent error (IAPE, Campana 2001) was 6.8% between readers and the overall coefficient of variation (CV) was 9.6% for the 100 otoliths read by two readers (Figure 6). There was some bias in zone counts, with one reader sometimes counting more zones, typically 1 or 2, than the other across the entire age range sampled. Of the 100 double readings, 48 were the same, 26 were different by 1 year, 12 by 2 years, 4 by three years, and 10 by more than 3 years. Several factors may have contributed to the differences in band counts.

> 1) The location of the first annulus was determined by measuring a standard distance (1.6 mm) from the origin and then selecting the nearest dark zone. Selecting the nearest appropriate zone could be subjective and generated some differences in the starting point for counting subsequent bands.
>
> 2) Zones between nos. 5 and 10 were commonly double or split. How these are counted can introduce differences in total counts. This would generate bias in all ages.
>
> 3) There are three axes along which zone counts can be made. The axis chosen for a given sample can vary between readers. In some cases switching axes can occur within one reading (usually when the inner part of one axis, and the outer part of another, is clearest). Different axes may yield different counts for all adolescent and older fish.
>
> 4) Some preparations are of poor quality which adds subjectivity in distinguishing between annuli and checks.

For samples where there was a disagreement noted, a consensus age was determined. Final ages used in the analysis were from R_1, who read all the otoliths. The effect of some discrepancies in age would be minimal in this analysis as ages were pooled for comparisons for older fish. However, a difference of one or two years in the ages of young fish (see below section 2.3.2) could in principle spread a strong year class into neighbouring ages, but this does not appear to be the case here.

2.3 Age structure comparisons

2.3.1 Age truncation

Comparisons of temporal changes in age structure were made for three regions (Tables 3 & 5). For the Southern region, 80 samples from 1993–1996 were compared with 144 samples from 2005–2007. A further 38 samples from the Northeastern region from 1999–2002 were available. The timing for this Northeastern collection lies between the early and late periods for the Southern region, but it is from a spatially distinct region and may provide some insight into regional differences in fishing intensity. Too few samples are available from the Western region in early years to form a group, and in later years, there are only 39 samples available, so a temporal comparison there was not conducted.

The 1993–1999 Kermadec samples indicated that more than 57% of the female fish observed were greater than 10 years of age (Figure 7, Table 6). This was the highest proportion observed (although captured with line gear), with a lower proportion (females only) captured with trawl gear in the Northeastern region (38%). Females from the Southern region in the early 1990s showed 13% of the observations greater than 10 years old and in the same region in 2005–2007 the proportion greater than 10 years old had dropped to 6%. This change (from 13% to 6%) spanning a decade, combined with the much higher proportions of older fish in the north, suggest a significant change in age distribution within the Southern region. Both Northeastern and Southern region samples were trawl-caught, although the target species for the Southern region is dominated by squid (SQU) target tows. We caution that changes in fishery (*e.g.*, gear or location fished) during that period could influence the encounter rate or the characteristics of häpuku encountered even though samples were derived from bycatch. No change in fishing distribution was apparent in either region with time. Selectivity aside, this potential change should be monitored in future age sampling programmes.

2.3.2 New recruits

Three groups were compared for potentially different signals in year class strength. The ideal pooling period was a single year so that year class strengths could be represented by the proportions at age. Significant annual samples were nearly always available for the Southern region, but only in 1999 for the Northeastern region, and in only 1998 and 2006-2007 for the Western region (Table 4). The best comparison among the three regions was made using 1999 data from the Northeastern and Southern samples, and 1998 data for Western samples (with the addition of a year to the Western ages for comparison).

Most of the recruit otoliths were from 3 year old fish (Figure 7). Seventy-three percent of Southern fish were three year olds, 24% were 4 years old, with only single 2 and 5 year olds present. Northern recruits were almost all 3 years old (93%), but this was likely to have been limited by the small sample size (14 fish).The reduction in sample size from listed samples was the result of the inability to match all the listed samples with physical otoliths. Western recruits were 3 years old (99%), but note that these samples were from 1998. Using the 3 year olds from 1998 to describe relative year class strength in 1999 is not possible because there were no younger fish present to estimate a relative proportion of 3 year olds expected in 1999. However, 3 year olds did dominate the samples in 1998 with only a single 4 year old present. Therefore, other than the difference in the ratio of 3–4 year olds between the Northern and Southern regions (7% versus 24%), the ability to compare recruiting year class strength is very limited with existing samples. Any future comparisons should use a larger threshold size to include more age classes and would likely need more samples within a year to accurately represent the proportion at each age.

3. BIOLOGICAL PARAMETERS

3.1 Growth rates

The study used a sample size twice that considered by Francis et al. (1999) for length-at-age analysis. However, most of the New Zealand mainland samples included in this analysis were trawl-caught fish, which tend to be younger individuals and therefore do not extend the length and age ranges from those already known. They also do not provide a useful age range to fit regional growth curves. Therefore, the von Bertalanffy growth curves are driven mainly by the larger range in ages observed in the Kermadec samples for each sex (Figure 8a). Males grow at about the same rate as females until about age 10, at which time male growth slows. Consequently, male maximum size is smaller than that of females. The oldest fish aged in the present study was 43 years (but this was excluded from the analysis in Table 7 as an outlier given the length of the fish), and the next oldest was 33. However, no fish in this study was more than 120 cm while Francis et al. (1999) report one fish of 147 cm aged 34 years, with the largest häpuku recorded as 178 cm. Adding data from Francis et al. (1999) provided older and larger fish for each sex, and showed higher L_{inf} values for the von Bertalanffy growth curve fits (Figure 8). Growth curve parameters for each sex from the Kermadec samples, as well as overall sex-specific parameters using all aged fish to date are given in Table 7.

3.2 Maturity

While conducting biological sampling of häpuku at sea, observers noted the maturity stage for a large percentage of females. Male maturity stage was not recorded. Female maturation status was recorded as one of five stages: Immature (F1), Maturing or Resting (F2), Ripe (F3), Running Ripe (F4), or Spent (F5). Because häpuku are believed to migrate to deep and/or untrawlable habitat for spawning, almost no records exist of verified “Running Ripe” females from research samples (Table 8). A 1986 *Shinkai Maru* bottom trawl survey of the Chatham Rise captured a number of fish in July that were maturing, with 14 of them in a single tow, but only a single female was staged as “Ripe”. This timing is comparable with the stages observed in other regions (though slightly early). Kermadec, Northeastern, and Western fish all showed ripe or running ripe stages of development in July–September (Figure 9). Samples from the ECSI showed a slightly later peak in September–November. Southern samples were mostly from January–April and showed few developing fish at that time of year. No large differences in the timing of spawning were detectable among regions.

Observer data were used to classify females as mature (F2–F5) or immature (F1) for each region to look for differences in the size at maturity. One problem with this approach is that resting fish and immature fish with some level of development are indistinguishable and both are classed as F2. Many very large females were classified by observers as F2 (even in samples during the spawning season) so this stage could not be treated as immature without making the spawning ogives meaningless. Larger (older) fish classified as F2 or even F1 may be skipping reproductive development in that year; if so, the proportion of the population spawning each year is less than the proportion scored as mature. Another potential bias with these data is that recording large individuals as F1 is counter intuitive, so large fish may be recorded by observers as F2 based solely on fish size. This is especially true when running ripe fish are not often encountered by observers. The only way to address this bias is through histological assessment of samples collected during the main developmental period (June–September). In this study, F2 females were considered to be mature.

Length at 50% maturity ($L_{50\%}$) was generally smaller in the north and larger in the south, though this was influenced by low sample sizes in some regions (Figure 10). No sensible ogive could be fitted to the Kermadec data. Low sample sizes and potential differences in fishery selectivity prevent meaningful curve comparisons, but Northeastern and Western regions were almost identical. The composite maturity ogive for all regions yields an $L_{50\%}$ of 82.6 cm, somewhat smaller than the 88 cm reported by Johnston (1983). Because of the problems associated with separating maturing and resting fish in a 5-stage system as described above, the true proportion spawning ogive could be further to the right because some resting fish would have been included as maturing in that year.

4. CATCH SAMPLING PLAN

4.1 Need for catch sampling

Although almost 6000 häpuku have been sampled for otoliths, the collections have been opportunistic, dominated by bycatch in the Southland squid trawl fishery (which selects small, young häpuku), and with relatively few samples within a given year from elsewhere. These constraints limit the comparisons of age structure that can be made and have provided limited information on possible age truncation and stock unit characteristics. Further work will require well-designed, dedicated catch sampling programmes.

Ageing more than 500 samples in a production mode was successful. The ability to age large numbers of häpuku using thin sectioning makes a catch-at-age analysis possible. Because of the relatively high longevity (more than 50 years, Francis et al. 1999), changes in age structure through time can provide useful stock unit identification and stock status information. Collecting the appropriate samples is now the critical link. Sampling häpuku to provide age composition information is complex because of the dynamics of the fisheries involved, their timing and selectivities, and species identification issues (i.e., separation from closely-related bass) that confound the ability to estimate species composition for historical catches, and the relatively low catches in each QMA.

4.2 Sampling plan development

The first step in designing a catch sampling plan is to describe where, when, and how häpuku and bass are caught. A basic fisheries characterisation was conducted to describe the fisheries. Data were groomed following the methods of Parker & Fu (2010). Because häpuku and bass are often minor components of the catch, estimated catches are significant underestimates of the total landed catch. Therefore the 'roll-up' method developed by Starr (2007) and modified by Parker & Fu (2010) was used to aggregate catch by statistical area, fishing method, and trip regardless of the reporting form used. These data were then used to summarize catch for each QMA to aid in the design of a catch-at-age sampling programme following the Ministry of Fisheries (2008) "Guidelines to the design, implementation and reporting of catch sampling programmes".

Designing a catch-sampling programme is typically done for each QMA as the programmes can be complex and expensive and must fit the characteristics of the regional fisheries. However, the objective of this project was to recommend a design for catch sampling programmes for all relevant QMAs. We recognize that a national catch sampling programme is unlikely to be implemented without a proven sampling approach and usable results. Therefore, our approach here was to describe the important strata to consider in designing a catch sampling programme for any area, and then to recommend a specific design for an initial area given those characteristics.

5. FISHERY CHARACTERISATION

Häpuku are landed mostly as HPB (groper, which includes both häpuku and bass), with some landed under the individual species codes HAP and BAS. Hence, the characterisation was conducted on the aggregate of all three codes. Paul (2002c) showed that there was no method available to post-stratify HAP and BAS reported landings into separate species. This is an issue that needs to be addressed in any future catch sampling programme. The desirability of separating häpuku from bass in the recorded catch and landing statistics should also be re-examined. Developing a method to allow retrospective estimation of HPB species composition based on location of catch would be most useful, and is now possible with the introduction of *Trawl Catch Effort Return* (TCER) forms which provide more precise fishing locations.

HPB has been divided into 8 Fishstocks (Figure 11). Although not exceeding the overall Total Allowable Commercial Catch (TACC), HPB landings have slowly increased since 1989, but decreased in the last two years driven mainly by catch decreases in QMAs 1, 4 and 7 (Figures 12 & 13; Table 9). Individual Fishstocks 1, 2, 3, 7 and 8 often met or slightly exceeded the TACC. Catches in HPB 4 and HPB 5 have been well below the TACC, although catch in HPB 4 has been growing in recent years, excluding 2009 (Figure 13). HPB 10 has had no significant landings since 1998 and is not discussed further.

HPB catch is reported mostly shallower than 200 m all around the North and South Islands of New Zealand, and also on the eastern and western Chatham Rise (Figure 14). It is not known exactly where catch occurred for HPB landings where no HPB catch was estimated for any of the tow locations of the trip (hence the light blue dots in Figure 14). Non-estimated landings are likely to be from sporadic bycatch on large vessels fishing the Chatham Rise or the Campbell Plateau. Most of the recent (2001–2009) catch results from fishing in nearshore statistical areas, especially 047, 018, and 022, though the east coasts of the North Island and South Island show significant catch in most statistical areas (Figure 15).

HPB landings are distributed fairly evenly among months at the national level, and landings within a QMA have been fairly consistent through time (Figure 16). Many ports are involved, with the top 15 ports still not representing more than all other ports combined. Port of landing is recorded in the Ministry of Fisheries *Warehou* database, however, a large number of misspellings or generic codes seriously limit the use of this important field. For example, more than 435 unique ports are listed for

HPB alone, often with values such as “port”. Simple grooming routines are not feasible for these spurious errors, meaning that error control at data entry is needed.

The main ports are near the statistical areas producing most of the catch, i.e., the east coasts of the North Island and South Island. Importantly, landings are split with regard to landed state, with almost half the catch consistently landed as green weight, the rest as headed and gutted or dressed.

Most of the catch has been reported on *Catch Effort Landing Return* (CELR or CEL in the database) and *Trawl Catch Effort Processing Return* (TCEPR) forms, though TCER (TCE in the database), *Lining Trip Catch Effort Return* (LTCER or LTC in the database) and *Netting Catch Effort and Landing Return* (NCELR or NCE in the database) forms have been used by many of these vessels from 2007–08 onwards (Figure 17a). The vessels landing HPB are typically small, in the 10–20 m overall length class and almost all flagged in New Zealand (Figure 17b, c).

One of the problematic features of sampling HPB is the identification of vessels to monitor. Many vessels are involved and even a ranked list of the top 100 vessels (by landings) shows only a few vessels with a stable landing history that could be used to allocate at-sea observer effort (Figure 18). This also means that any industry-led sampling programme to collect samples would need high levels of participation across multiple gear types to obtain representative samples (both spatially and relative to level of catch).

6. STRATIFICATION

Figures 19–25 show the distributions of catch for the past nine years in each QMA in relation to month, statistical area, fishing method, target species, port of landing and landed state. The purpose of these figures is to identify the major factors to consider when designating strata for a catch sampling programme in each QMA. The following discussion identifies the strata necessary and potential approaches to sampling those strata. An initial design for the first sampling programme will then be described as a recommendation.

6.1 Recreational versus commercial catch

Table 9 shows that each QMA typically records commercial catches in the range of 200–500 t. The most recent national catch estimates for recreational häpuku/bass catch are also in this range, though the c.v.s for these estimates are high and the data are now a decade old (Boyd and Reilly 2002, Ministry of Fisheries 2010, Table 10). A recreational catch sampling programme could be used to scale total removals if the recreational selectivity for each area is known. Because recreational catches of HAP, BAS, or HPB are not known, our design here will focus on commercial catch sampling only, but we note that considering recreational catch magnitude and age composition (along with selectivity) should be included when interpreting any commercial sampling results.

6.2 Fishstocks

Given that the characteristics of some QMAs are similar, and there is no current information suggesting there are unique stocks in each QMA, it may be feasible to combine some QMAs to minimize cost and reduce the number of samples needed. However, by combining QMAs, the subsequent analysis would lose the ability to discriminate differences in age structure between areas if they do exist. Potential QMAs to combine are 1 & 2, 7 & 8, and 3 & 4. Our recommendation is to keep QMAs separate until they have been shown to be similar in age structure and other characteristics, and then merge some at a future date.

6.3 Sampling approach

Only HPB 1 is dominated by greenweight landings (although they are common in HPB 2), so sampling would need to be conducted through an at-sea observer programme in most QMAs. Landings are spread among multiple ports within each QMA and the proportion landed in each port is variable through time (Figures 19–25). But given the predominance of processed fish and the objectives to collect otoliths, incorporate häpuku versus bass catch ratios, and record location of capture, at-sea observation will be necessary, perhaps even for HPB 1, as the catch there is often not recorded under estimated catch (*i.e.,* catch is small and/or infrequent). The use of the TCER form may help with this issue because the top eight species in the catch may now be reported.

6.4 Cooperative industry sampling programme

Given the complexities of sampling small numbers of fish from many landings, a sampling approach that utilized industry logistical support to collect specimens or the data and samples themselves from targeted fish as they were caught could be beneficial. There are several negative and positive aspects of this approach to consider.

On the positive side, if vessel crew could sample the fish, collect otoliths, and collect location information, there would be significant cost savings in that no onshore sampler would be necessary. Observer placement would not be necessary, and the resulting samples and data could be subsequently filtered to ensure appropriate spatial and catch stratification.

An intermediate option would be for vessel crew to label each fish with a location of capture and retain them separately and whole for subsequent sampling once landed. This option would also avoid the need for at-sea observers. It does not save onshore sampling costs, but does provide some useful information.

On the negative side, sampling or even annotating catch, separating it and landing it whole would add a significant time cost for vessel crew. More importantly, because the occurrence of häpuku or bass is sporadic, representative catch and spatial sampling would require a large proportion of the vessels spanning several gear types in each area to participate. And if catch is simply landed, then a shore-based sampler is still needed to sample large numbers of small landings.

6.5 Statistical area

With at-sea observer sampling, the tows or sets sampled could be defined by statistical area. However, Figures 19–25 show that the statistical areas where catch occurs have been variable among years in QMAs 1, 4, 5 and 7, but relatively stable in QMAs 2, 3 and 8. It may therefore be simplest to aggregate statistical areas into broader regions. Within statistical area, there is concern that häpuku and bass may associate with specific topographic features, and therefore catch sampling should track the actual locations of capture as this may influence species composition, estimates of fishery selectivity, and potentially population identification.

6.6 Season

Häpuku catch comes mainly from bycatch in fisheries for other target species, so landings are spread throughout the year, but with somewhat higher catches in summer months in some QMAs (Paul 2002b). The seasonal pattern in catch for each QMA is shown in Figures 19a–25a. The northern and southern seasonal peaks are August–September and February-May. The Kaikoura peak is May–July. A weak Cook Strait peak occurs in April–May, but is spread among four QMAs. There is a small September peak in many areas, which possibly represents fishers targeting the spawning migration or targeting HPB to use up their fishing year's quota. Stratifying catch with regard to season could be accomplished with two strata (winter and summer) in most areas. The winter season would be likely to include most of the targeted fishing, which occurs in the August–September spawning season.

6.7 Depth

HPB catch is often not estimated on TCEPR forms, or is reported on CELR forms, so the catch data cannot be directly linked to fishing depth. HAP typically (but not exclusively) has a shallower depth distribution compared with BAS and these two species should be sampled simultaneously to allow the proportion of catch by species to be determined for each species in relation to depth for each area. Almost all fishery data are reported as HPB. Research sampling does not combine häpuku and bass, but it is limited in the gear used (almost all trawl gear) and therefore the habitat types sampled. Stratifying observer sampling by depth is likely to be difficult to implement as required sample sizes could not easily be predicted relative to future effort by depth. Alternatively, the relationship between depth and species could be estimated through time by post-stratification of TCER, LTCER, and TCEPR data if landings were recorded by species.

Depth is also important because häpuku and/or bass may migrate from juvenile habitat to deeper adult habitat, or may slowly disperse from source to sink areas which would show an increase in age along the route. Accurate monitoring of age structure will require targeting both the depth category sampled and area sampled.

6.8 Primary Method

Several gear types commonly capture HAP and BAS, but the relative proportions of catch from each method varies by region and gear type must be used as strata (Figure 26). The major gear types are BLL (bottom longline), DL (drop line), BT (bottom trawl), SN (set net), and to a minor degree MW (midwater trawl) in QMA 5.

6.9 Target species

The dominant species targeted when HPB is captured also varies by region and gear type, but is typically HPB, bluenose (BNS, *Hyperoglyphe antarctica*), ling (LIN, *Genypterus blacodes*), tarakihi (TAR, *Nemadactylus macropterus*), red cod (RCO, *Pseudophycis bachus*), squid (SQU, *Nototodarus sloanii* & *N. gouldi*), or school shark (SCH, *Galeorhinus galeus*). The actual target species included in a stratum will need to be determined for each QMA and by primary method (Figure 26). In most cases, sampling two or three gear types would be required.

6.10 Vessel

A large number of vessels land HPB each year, and because it is not a major target species, the proportions landed by particular vessels each year are extremely variable. Therefore, it is probably not feasible to place observers on particular high-catch vessels because these vessels typically cannot be predicted. Observer effort should be allocated based on primary method and target species within each QMA.

6.11 Vessel size

An additional constraint on sampling HPB catch at sea is that the vessels landing most of the HPB catch are relatively small vessels, mostly in the 10–25 m range (see Figure 17). Placing observers on smaller vessels can be a challenge and because the catch rates for HAP or BAS are not predictable (unless a vessel makes a pre-determined targeted HPB trip) many days at sea would be required to obtain the samples sizes needed for each gear type and target species.

6.12 Sample size

No previous data are available to estimate mean weighted c.v.s of the age structure for a given sample size, and the age compositions are likely to vary dramatically with gear type given the different fish sizes targeted or captured. Because HAP and BAS catches are relatively uncommon, prescribing sample size per landing is not warranted. A relatively large number of samples will be required because fish are encountered from age 3 to 50, potentially generating more than 40 age classes. The best approach to sample uncommon species is to sample every fish encountered up to 10 fish per haul for age (otoliths), with length and sex sampled for all additional fish observed. After the first catch sampling programme has been conducted, data will be available for an analysis to estimate appropriate sample sizes for future sampling programmes. However, to a significant degree, the variability in the numbers of trips in each QMA each year, the gear types used, and the species targeted will constrain the ability to accurately predict c.v.s. As general advice, typical catch sampling programmes target 30-50 samples of 50 fish. In this case, because only a few fish will be sampled from each landing, targeting an initial total sample of 200 individuals per stratum may be necessary to provide a reasonable initial c.v..

6.13 Bass

Most catch is landed as HPB, and is from near shore statistical areas. It is likely that most of the landed catch is häpuku. However, different fishery sectors, especially in northern waters where bass are more common, and larger vessels in deeper water do catch bass. The best way to address this issue is to collect data at sea relative to the species encountered, the depth, and fishing method. If a catch-at-age sampling programme specifically for BAS is desired, the same features as described above for HAP would be required because species data are not separable and it would make sense logistically to conduct both sampling programmes at the same time. Estimating the relative catch by QMA and fishery sector (or statistical area) would also allow the two species to be split in the Quota Management System and would lead to species-specific catch records, better stock status information, and better management options.

6.14 Kaikoura set net fishery

A unique, seasonal fishery targeting häpuku exists off the East Coast of the South Island, especially off Kaikoura. It is described separately here as it is a discrete unit that could provide sampling opportunities for characterising HPB 3 populations. The fishery is small, typically fewer than 10 vessels in the 5–10 m length class and most landings are less than 100 kg. It occurs mostly in statistical area 18 in May–July and specifically targets HPB, although some LIN and TAR fishing also results in HPB landings (Figure 27). The distribution in time and space of catches has been stable throughout the time series, but with a small trend towards lower catches in recent years. The timing of the fishery is early relative to spawning, but the fish appear to migrate through the area (authors' unpublished data). The main problem with obtaining samples from this fishery is that fish are landed processed and vessels are too small to take observers without special accommodations. Therefore, fish would probably need to be brought to shore whole for sampling and that may in turn create space problems on the small vessels. Organising vessel crew to sample otoliths, stage gonads, and maintain accurate records and metadata in addition to normal duties at sea introduces additional problems, though it could eliminate the need for sampling on shore for this small fishery.

7. RECOMMENDATIONS

Given the several stratifications needed, unknown c.v.s on age distributions, the need for observer coverage, and the size of a New Zealand-wide sampling programme for HAP and BAS, we designed an initial catch sampling programme for a single QMA. Results from a single QMA could then be used to more accurately scale a catch sampling programme in other QMAs.

Initially, catch sampling programmes should be designed for individual QMAs until stock structures are shown to be similar. Subsequent sampling could then be conducted on pooled QMAs regions as supported by stock unit data.

QMA 1 typically has the largest HPB landings. It also has the highest proportion of HPB landed whole, so much of the sampling can occur at processors' sheds on shore, minimizing cost and maximizing data. A major problem with sampling landings is that most landings are small and unpredictable in timing, so sampling will need to be opportunistic with no minimum landing weight and many landings will need to be sampled. For example, in 2009 in QMA 1, there were1880 landings of HPB totalling 338 t, but 75% of the landings were less than 100 kg. Also, the target species may or may not be known by a sampler at the time of landing, although most landings in HPB 1 are HPB target (which could be HAP or BAS). If possible, sampling 25% of the fish from BNS target trips would be representative because 25% of the landed HPB catch is generated by BNS target fishing. Other target species were minor contributors. Most HPB targeting was done with bottom longline, though a minor proportion was conducted with drop line (Figure 19, 26).

Given the complexity of sample stratifications, the simplest and potentially most cost effective sampling programme for HPB 1 may be to identify a port and month and work with processors to sample every häpuku/bass landed whole as this would probably be just a few fish per landing. Overall, this would result in a representative sample of statistical area, gear type, and target species in proportion to landed weight, but would require samplers to be available for short periods of work almost year around. This assumes that the individual fish processed at sea are not chosen by fishers based on fish size or stratum.

Sampling strata for HPB 1 would be:

Month	%	Gear type	%	Target Species	%	Port	%
Oct-Nov	20	BLL	75	HPB	75	Mangonui	35
Dec-Jan	20	DL	25	BNS	25	Totara N.	35
Feb-Mar	10					Auckland	30
Apr-May	10						
Jun-Jul	10						
Aug-Sep	30						
Total	100		100		100		100

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Table 1: Häpuku otolith sample collections (number of otoliths) by calendar year and management area as of August 2008, including both Observer Programme and Research collections.

Year	Auckland east (QMA 1)	Central East (QMA 2)	SE coast (QMA 3)	SE Chatham (QMA 4)	Southland (QMA 5)	Sub Antarctic (QMA 6)	Challenger (QMA 7)	Central Egmont (QMA 8)	Auckland west (QMA 9)	Kermadec (QMA 10)	Southern Islands (SOI)	Challenger (ET)	Grand Total
1979		8						46					54
1980			49										49
1981			10						2				12
1982			1				1						2
1987	18					5							23
1988	3					4							7
1989	9												9
1993					225	4	5	1	4	11	1	30	281
1994					154		2	2					158
1995	1		1	24	174		19	68					287
1996	5	7	10		149		6			65	3		245
1997		6	1		2				4	18	27		58
1998			7	34	114		11	100	42	58			366
1999		80	67		179	7	18			4	7		362
2000	2	48	54	45	262		106						517
2001		33	54	16	284		37				2		426
2002		43	43	31	279		16		4		20		436
2003		15	27	79	403	4	33				4		565
2004	1	3	17	7	330	16	4				13		391
2005		25	8	10	626	5	26	1					701
2006	1	6	19	15	288		12	28	4		3		376
2007		26	58	16	250		25	42					417
2008				57	54		5				4		125
Total	40	300	426	334	3773	45	326	288	60	156	84	30	5 867

Table 2: Häpuku otolith sample collections by gear type and region (number of otoliths) as of August 2008.

	Fishery					
Region	Bottom longline	Drop line	Bottom trawl	Midwater trawl	Not specified	Grand Total
Southern	108	9	1 883	1 849	58	3 907
East coast SI and Chatham Rise	194	60	417	89		760
Western			269	242		511
Northeastern	60	8	220	12		300
Kermadec		152			4	156
Cook Strait		103				103
Northern		36	59	4	1	100
Challenger		30				30
Grand Total	362	398	2 848	2 196	63	5 867

Table 3: Numbers of female häpuku greater than or equal to 75 cm sampled in bottom and midwater trawl fisheries each year since 1993 within three large regions around New Zealand. Boxes indicate groupings for age structure comparisons of the older (adult) portion of the population in each region. Total samples highlighted = 264. Samples as of August 2008.

Year	Northeastern	Western	Southern	Grand Total
1993		2	34	36
1994		1	20	21
1995		11	19	30
1996	2	1	9	12
1997	2		5	7
1998		6	14	20
1999	9	8	18	35
2000	10	20	19	49
2001	5	18	32	55
2002	14	5	26	45
2003		18	58	76
2004	1	2	58	61
2005	2	12	100	114
2006		12	22	34
2007		15	22	37
Grand Total	45	131	456	632

Table 4: Numbers of häpuku less than 65 cm sampled in bottom and midwater trawl fisheries each year since 1993 within three large regions of New Zealand. Boxes indicate groupings for age structure comparisons of the recruit age (juvenile) portion of the population in each region. Total samples highlighted = 233. Samples as of August 2008.

		Region		
Year	Northeastern	Western	Southern	Grand Total
1993		2	81	83
1994			50	50
1995		5	53	58
1996			34	34
1997			9	9
1998		92	28	120
1999	57	5	84	146
2000	18	16	145	179
2001	5	2	88	95
2002	5	2	84	91
2003	4	2	166	172
2004		1	93	94
2005	7	1	146	154
2006		19	82	101
2007		25	67	92
2008		4		4
Grand Total	96	176	1 210	1 482

Table 5: Numbers of samples available for each year and region, along with size and sex constraints for comparison of ages. Note: the actual samples with ages are somewhat different to Tables 3 and 4 due to lost samples, poor sample preparations, or missing metadata. DL, Drop line; BLL, Bottom long line; TROT, Trot line.

Region	Years included	Number sampled	Fishing method	Size, sex constraint
Kermadec	1993-99	152	DL,BLL,TROT[1]	None
Northeastern	1999-2002	38	Trawl	>= 75, F
Southern (early)	1993-96	80	Trawl	>= 75, F
Southern (late)	2005-07	144	Trawl	>= 75, F
Northeastern-Recruit	1999	57	Trawl	< 65 cm
Western-Recruit	1998	92	Trawl	< 65 cm
Southern-Recruit	1999	84	Trawl	< 65 cm
Total		647		

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[1] All Kermadec fish with known sampling years were selected. No Kermadec fish were sampled with trawl gear.

Table 6: Proportion of fish (females, greater than or equal to 75 cm) more than 10 years old in each region or period. Note: Although more Kermadec samples were aged, samples were screened to include only females greater than or equal to 75 cm in length for this comparison.

Region	Period	Proportion >10 years
Southern	1993–1996	0.133
Southern	2005–2007	0.058
Northeastern	1999–2002	0.379
Kermadec	1993–1999	0.576

Table 7: Summary of von Bertalanffy growth curve fits for male and female häpuku from the Kermadec region, fish from Francis et al. (1999), and all regions combined (including data from Francis et al. (1999)). Note: one Kermadec fish was aged at 43 years old, but with a length of 82 cm was excluded as an outlier.

Group	N	L_{inf}	K	t_0
Kermadec				
Male	67	99.28	0.1497	-3.07
Female	72	109.96	0.1253	-3.19
Francis et al. (1999)				
Male	105	129.20	0.0618	-5.75
Female	110	133.20	0.0698	-4.30
All samples				
Male	210	123.94	0.0678	-6.10
Female	439	125.55	0.0804	-4.68

Table 8: Biological details of individual female häpuku with gonad stage greater than 3 (ripe through spent) captured during research trawl surveys. Note: Research surveys used a 7 stage classification system, where 3 is maturing, 4 is ripe, 5 is running ripe, 6 is partially spent, and 7 is spent.

Trip code	Station	Fish number	Length (cm)	Weight (g)	Gonad weight (g)	Gonad Stage
shi8602	52	10	100.0	16 000	1580	4
tan9402	21	1001	121.3	26 400		6
tan9402	124	3001	109.8	19 000	349	6
tan9402	124	3002	91.9	13 400	250	6
tan0301	97	1001	73.4	5 900	51	4
tan0317	80	1001	97.5	13 400		7
kah0506	23	4	71.9	4 300		7
tan0714	70	1001	104.2	13 600	197	5
tan0813	80	1006	105.3	14 700		7
tan0911	92	1001	98.6	12 500		7

Table 9: Häpuku/Bass landings and TACC for each QMA from 1984 to 2009. NA indicates no catch reported.

Fish year	HPB 1 Landings	HPB 1 TACC	HPB 2 Landings	HPB 2 TACC	HPB 3 Landings	HPB 3 TACC	HPB 4 Landings	HPB 4 TACC	HPB 5 Landings	HPB 5 TACC
1984	974	NA	493	NA	505	NA	55	NA	395	NA
1985	642	NA	388	NA	418	NA	52	NA	228	NA
1986	569	NA	270	NA	391	NA	53	NA	126	NA
1987	238	360	179	210	260	270	42	300	131	410
1988	248	388	202	219	268	286	43	315	91	414
1989	231	405	187	248	259	294	49	315	70	425
1990	310	465	179	263	283	318	40	322	127	430
1991	350	480	225	263	311	326	77	323	120	436
1992	277	480	252	263	298	326	58	323	112	446
1993	375	480	273	264	299	327	68	323	128	446
1994	363	480	287	264	306	330	90	323	147	446
1995	334	481	259	264	274	335	149	323	161	451
1996	335	481	214	264	321	335	173	323	144	451
1997	331	481	234	264	301	335	131	323	149	451
1998	375	481	260	266	329	335	88	323	91	451
1999	433	481	256	266	348	335	121	323	97	451
2000	471	481	229	266	385	335	66	323	169	451
2001	450	481	220	266	381	335	45	323	188	451
2002	427	481	226	266	343	335	82	323	169	451
2003	442	481	273	266	350	335	79	323	212	451
2004	433	481	281	266	335	335	87	323	166	451
2005	433	481	263	266	371	335	147	323	208	451
2006	425	481	280	266	406	335	185	323	167	451
2007	483	481	243	266	394	335	222	323	157	451
2008	439	481	253	266	341	335	241	323	138	451
2009	338	481	228	266	377	335	138	323	149	451

(continued)

Table 9: Continued.

Fish year	HPB 7 Landings	HPB 7 TACC	HPB 8 Landings	HPB 8 TACC	HPB 10 Landings	HPB 10 TACC	Total Landings	Total TACC
1984	174	NA	46	NA	0	NA	2698	NA
1985	207	NA	33	NA	0	NA	2039	NA
1986	199	NA	25	NA	0	NA	1697	NA
1987	149	210	35	60	0	10	1036	1830
1988	158	215	66	76	0	10	1076	1923
1989	132	226	39	78	1	10	968	2001
1990	119	229	43	80	0	10	1098	2117
1991	128	235	48	80	23	10	1282	2153
1992	175	235	50	80	83	10	1319	2163
1993	186	236	62	80	22	10	1405	2165
1994	193	236	69	80	0	10	1455	2167
1995	192	236	68	80	0	10	1437	2179
1996	214	236	78	80	0	10	1479	2179
1997	186	236	71	80	15	10	1418	2179
1998	147	236	60	80	33	10	1406	2181
1999	218	236	78	80	3	10	1562	2181
2000	165	236	65	80	0	10	1561	2181
2001	171	236	64	80	0	10	1519	2181
2002	204	236	62	80	1	10	1514	2181
2003	233	236	72	80	0	10	1661	2181
2004	239	236	66	80	0	10	1607	2181
2005	240	236	80	80	0	10	1742	2181
2006	207	236	56	80	0	10	1728	2181
2007	206	236	66	80	0	10	1725	2181
2008	195	236	44	80	0	10	1651	2181
2009	189	236	70	80	0	10	1489	2181

Table 10: Results of the Dec 1999–Nov 2000 national diary survey of recreational fishers. Estimated number of groper (häpuku and bass) harvested by recreational fishers by QMA, and the corresponding harvest by weight. Estimated harvest is presented as a range to reflect the uncertainty in the estimates (Boyd & Reilly 2002).

Fishstock	Number caught	CV (%)	Harvest range (t)	Point estimate (t)
HPB 1	60 000	39	209–476	342
HPB 2	56 000	33	307–608	457
HPB 3	52 000	50	97–293	195
HPB 5	6 000	70	14–80	47
HPB 7	17 000	37	79–172	125
HPB 8	2 000	67	6–32	19

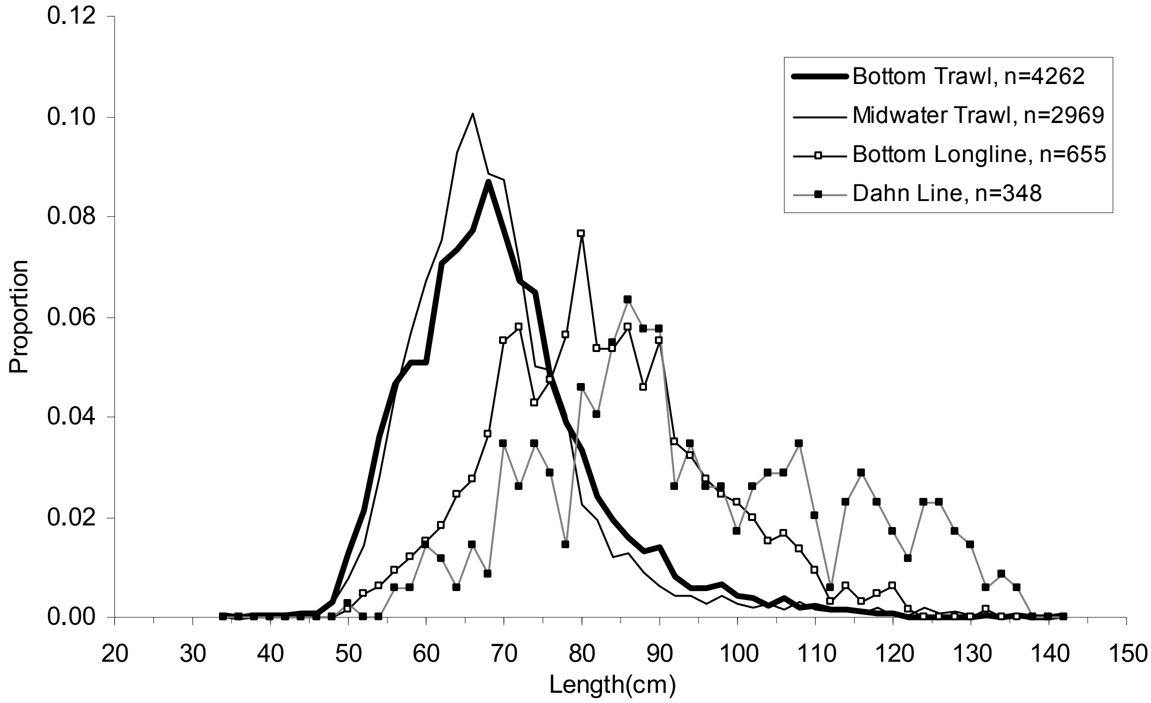


Figure 1. Length distributions for häpuku sampled by the Observer Programme for four gear types (1987-2008).

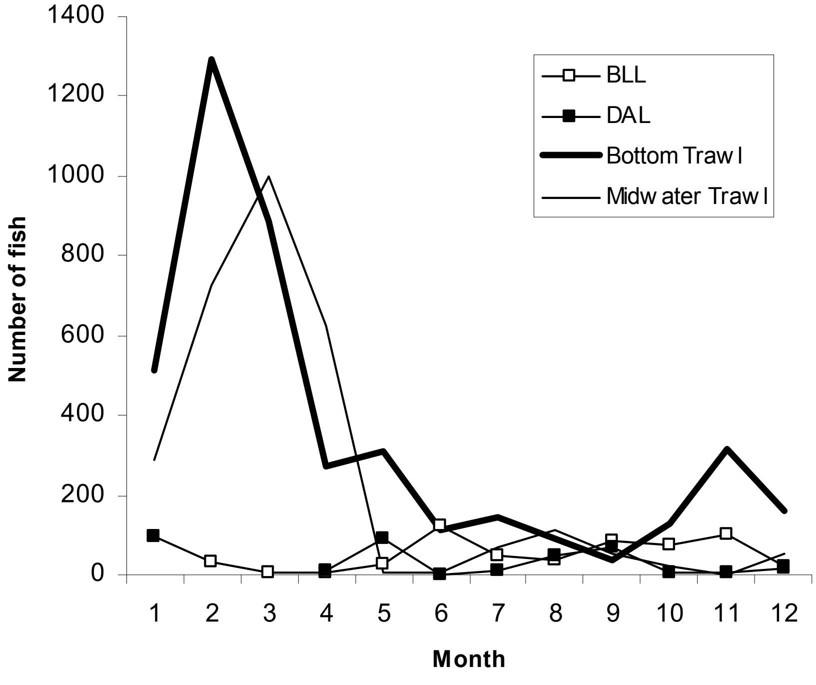


Figure 2. Numbers of häpuku sampled by the Observer Programme by month and gear type (1987-2008). BLL, Bottom long line; DAL, Drop line.

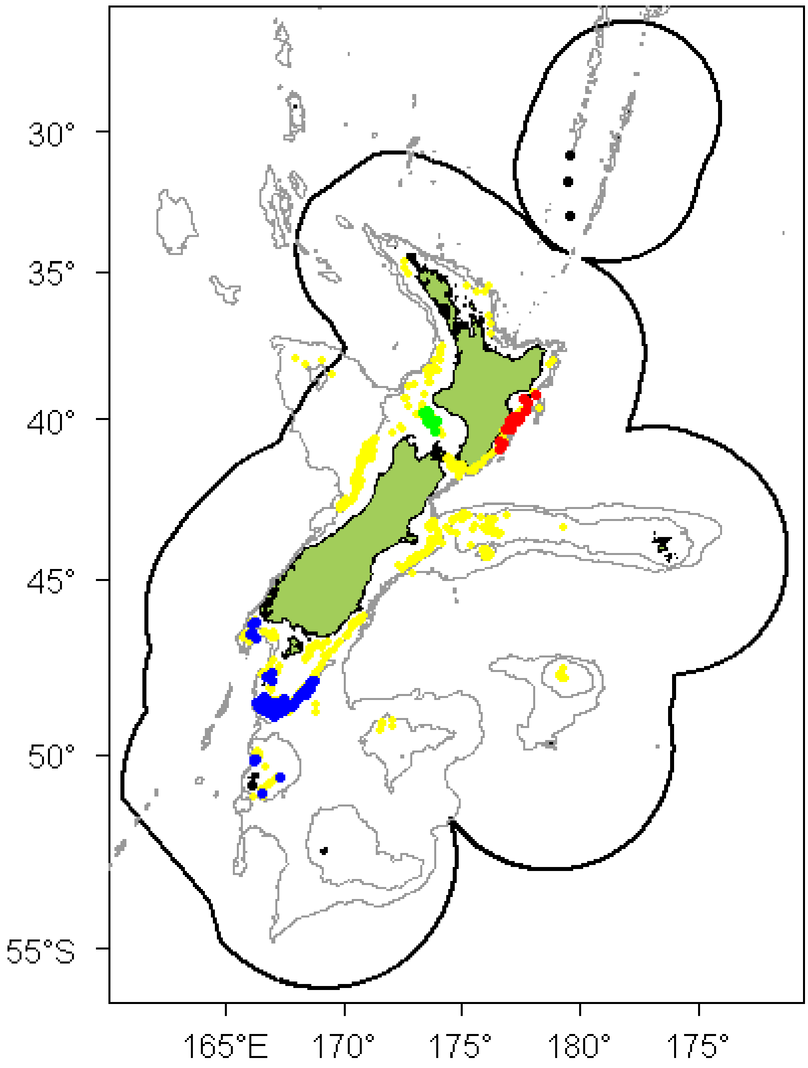


Figure 3. Location of häpuku otolith samples obtained by the Observer Programme (1987-2008, yellow), overlaid with positions of samples selected for ageing from four regions: Southern (blue), Northeastern (red), Western (green), Kermadec (black). Note: some Kermadec samples did not provide actual catch positions and are not shown.

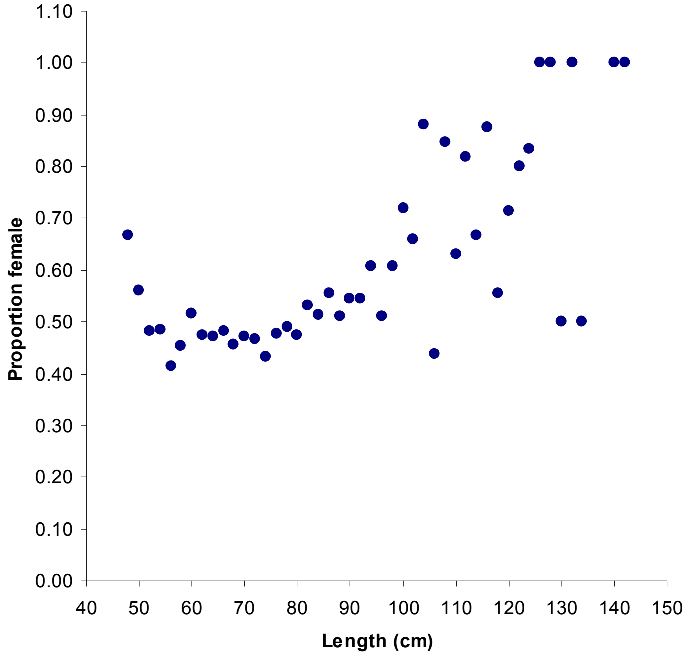


Figure 4. Proportion of females in all biological samples (all gear types and regions combined) of häpuku in relation to length.

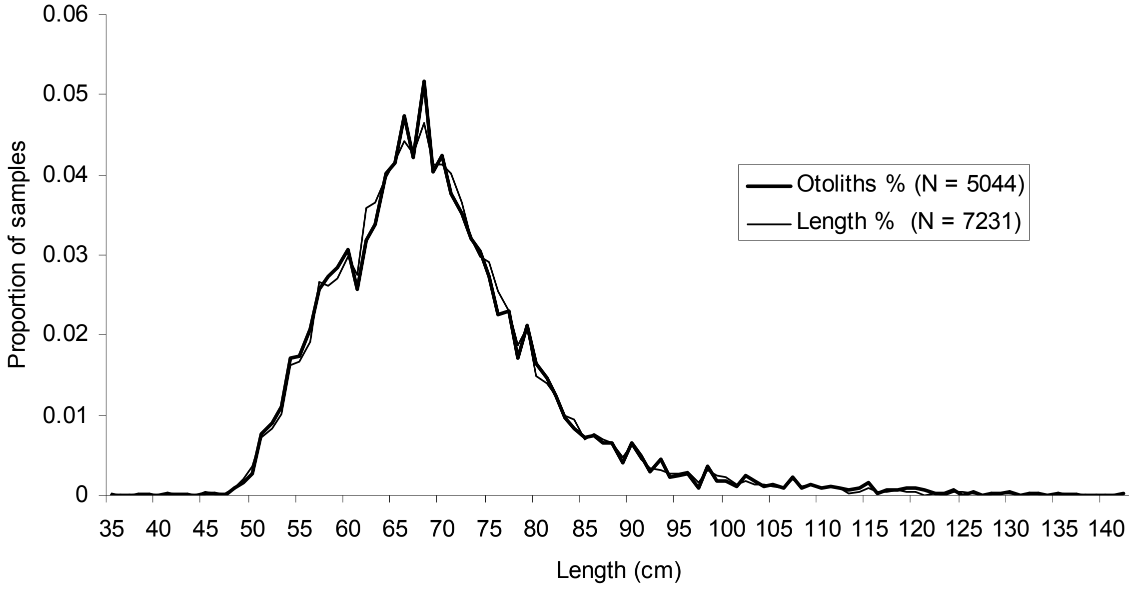


Figure 5. Relative frequency distribution of lengths for häpuku sampled for size only (thin line), or for size and otoliths (thick line) from the observer database.

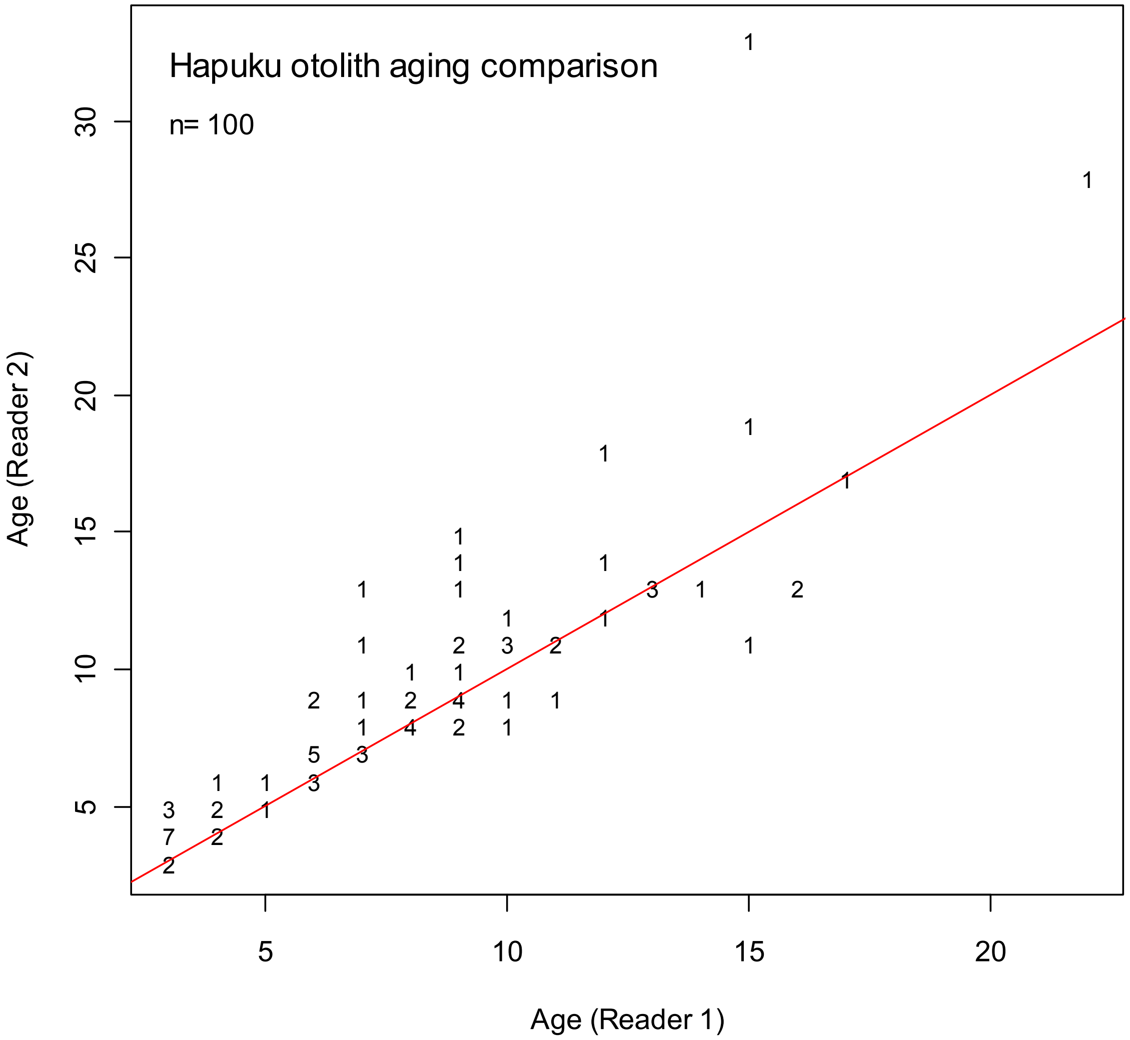


Figure 6. Comparison of häpuku ages (n=100) determined by two readers. The complete agreement line is shown in red. Plotted symbols indicate the sample size for each point. The disagreement in age 15 versus 33 is due to the presence of many split bands in this otolith section, which one reader interpreted as annuli.

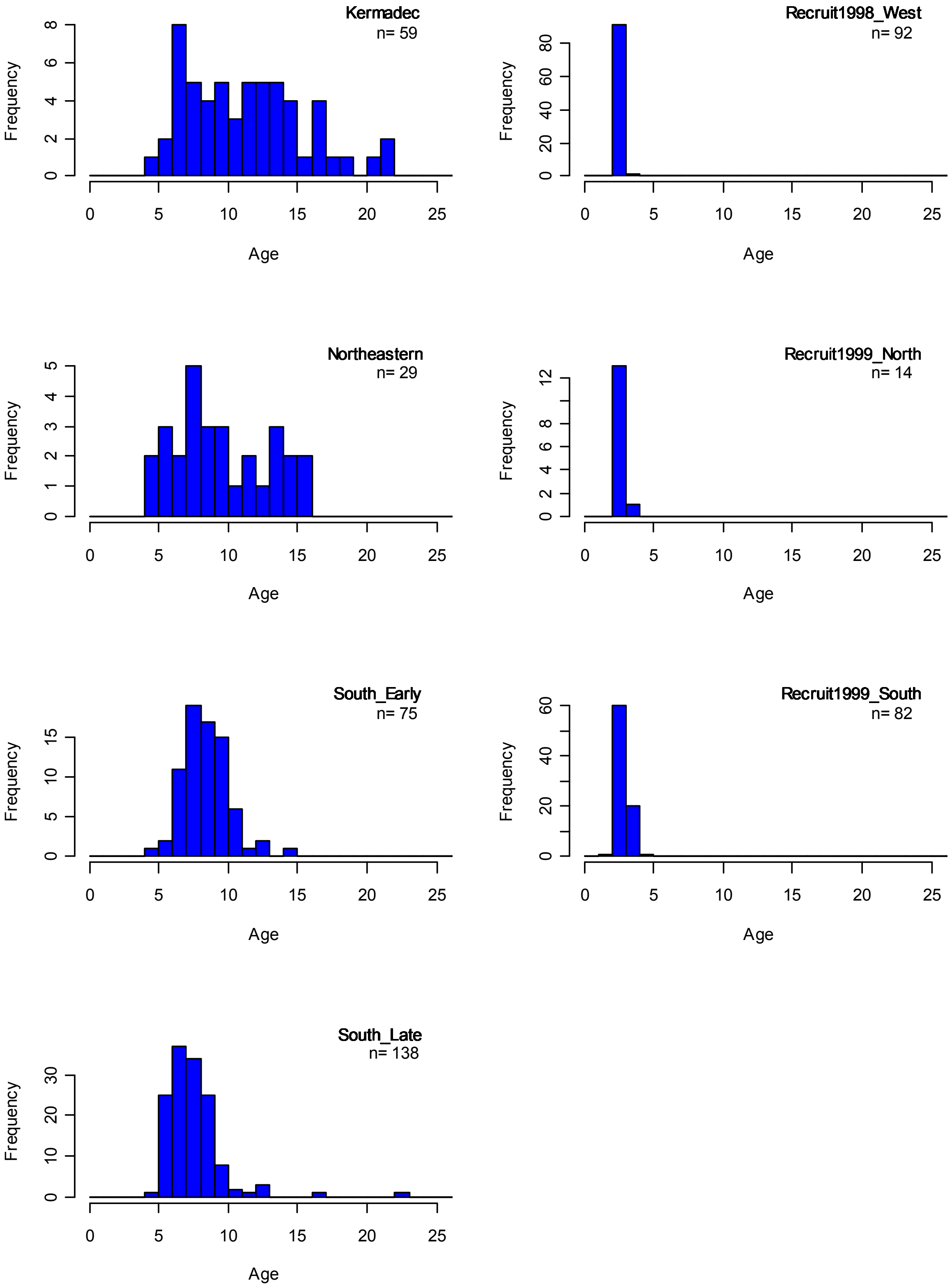


Figure 7. Distribution of ages determined from each regional subsample of otoliths aged. Note that each subsample was chosen relative to sex, size, gear type and period for comparison. See Table 5 for a description of the sample selection criteria. For comparative purposes, only females greater than or equal to 75 cm are shown for the Kermadec region and two fish (30 and 43 years old) are not shown. The actual number of samples with ages determined are somewhat different to Tables 3–5 due to lost samples, poor sample preparations, or missing metadata.

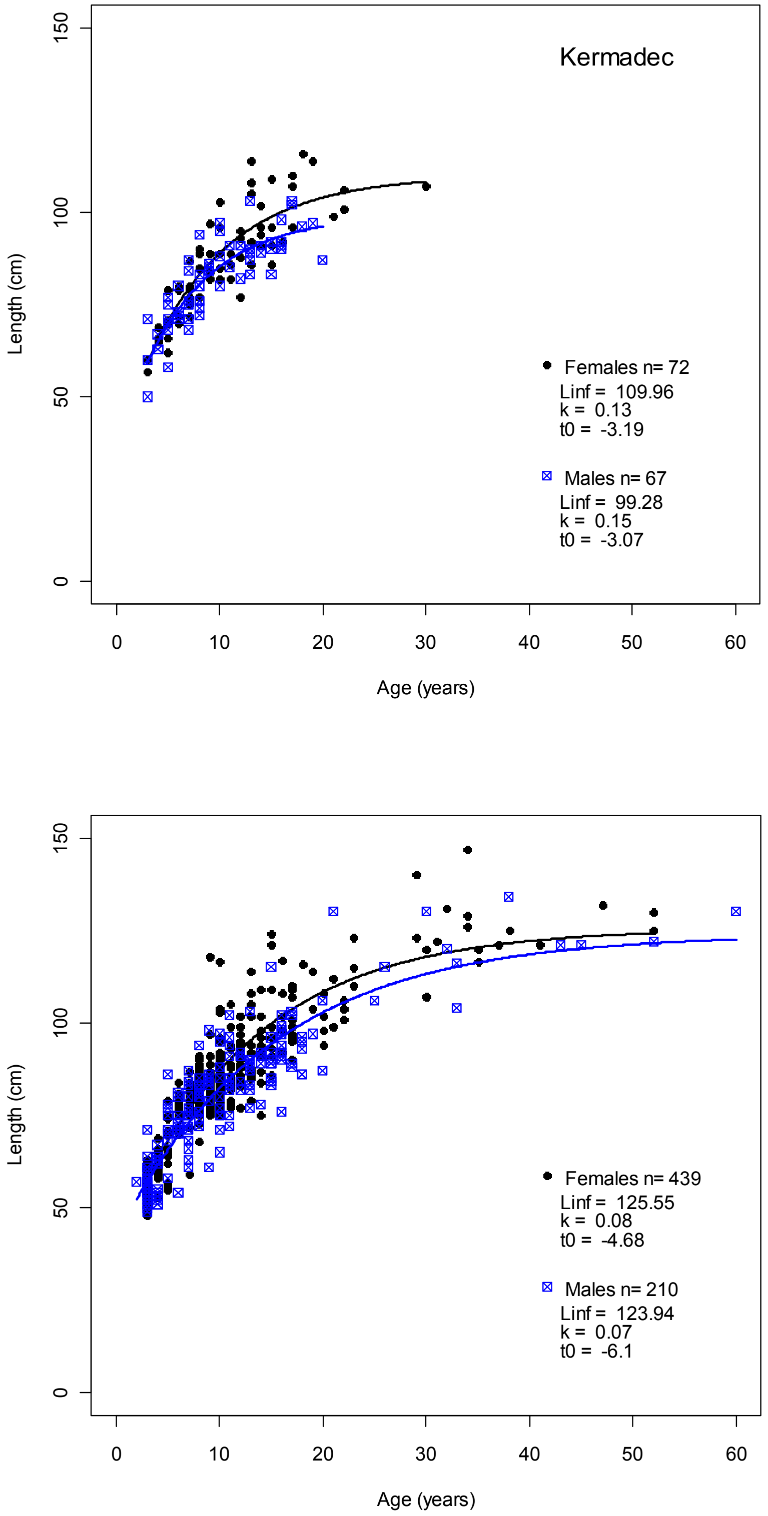


Figure 8. Von Bertalanffy growth curves for male and female samples aged from the Kermadec region (top panel) and composite fits for all males and females, including data from Francis et al. (1999) (bottom panel).

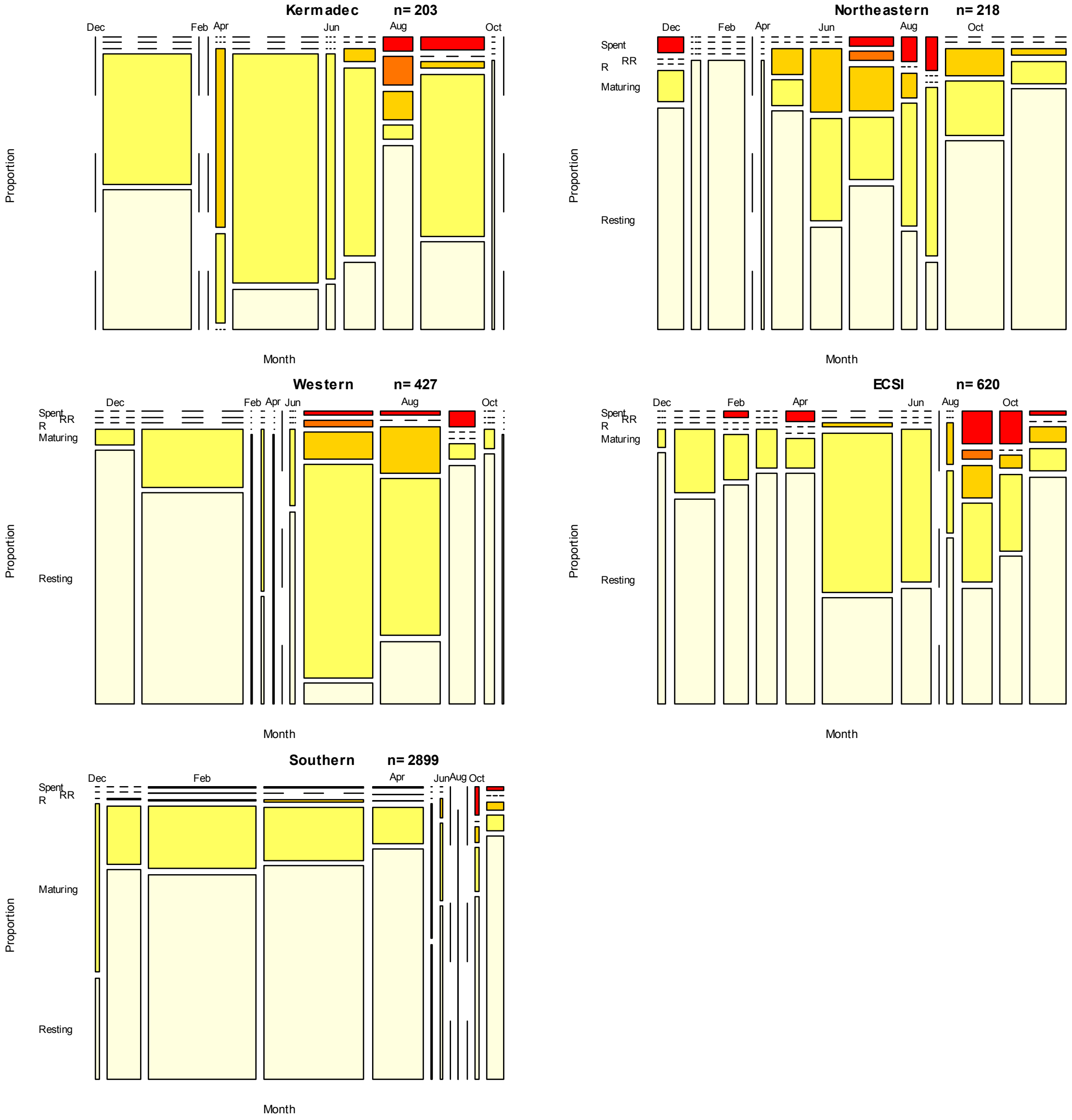


Figure 9. Proportion of female häpuku observed by maturity stage and month for five regions. Bar width is proportional to sample size for each month. Bar height is the proportion of samples in a particular stage. Bars are shaded for each stage from yellow (maturing) through to red (spent). Note: Immature fish (F1) were excluded to emphasize the period of gonad development. R, Ripe; RR, Running Ripe.

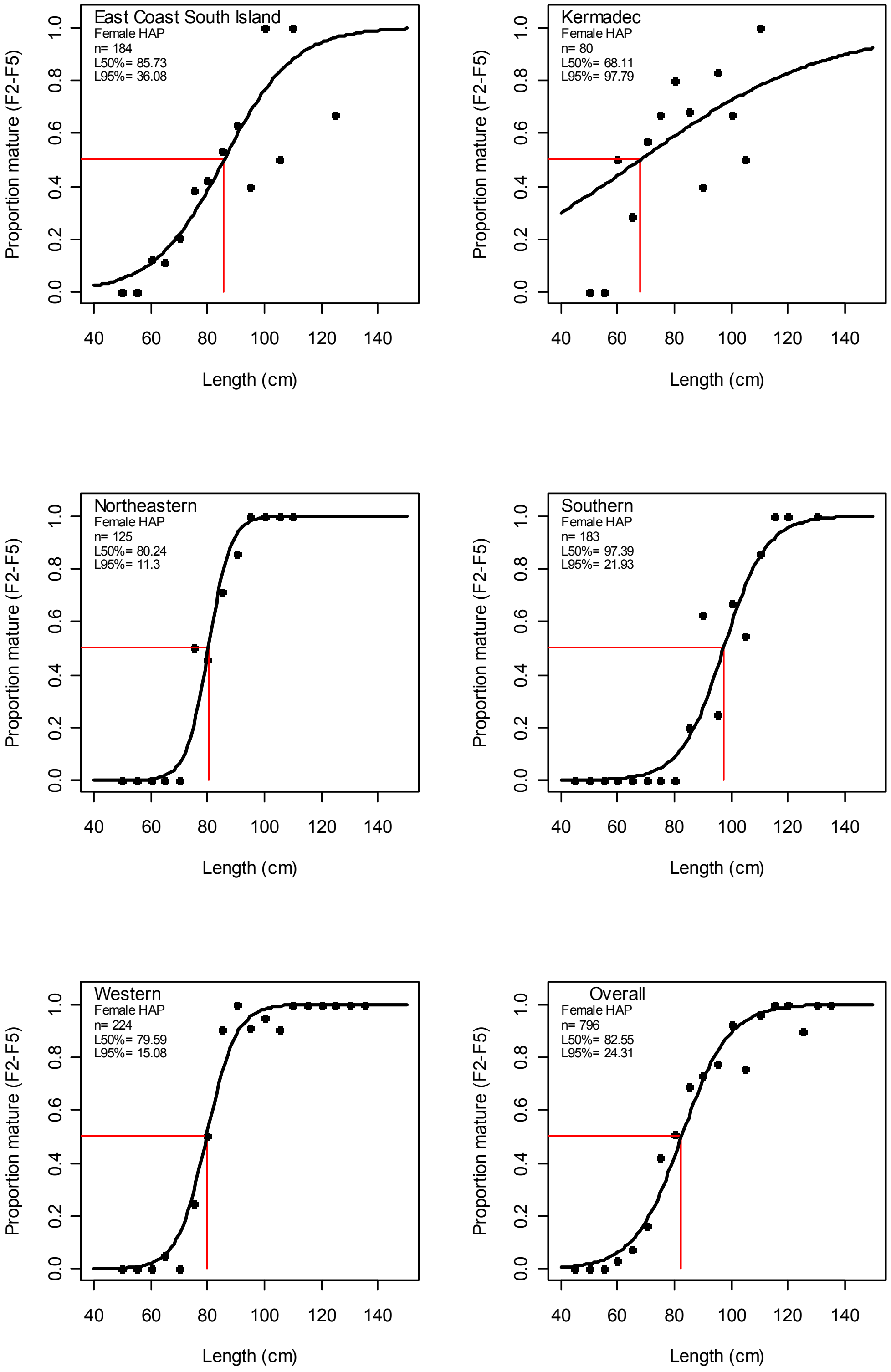


Figure 10. Female häpuku length at maturity ogives (with observed proportions shown as dots) for five regions based on observer data. The Overall ogive is a composite of all data. $L_{50\%}$ is the length at 50% spawning (indicated by red line). $L_{95\%}$ is the value to be added to the $L_{50\%}$ to estimate the length at 95% spawning. Note: a single 120 cm immature female was omitted from the Kermadec data.

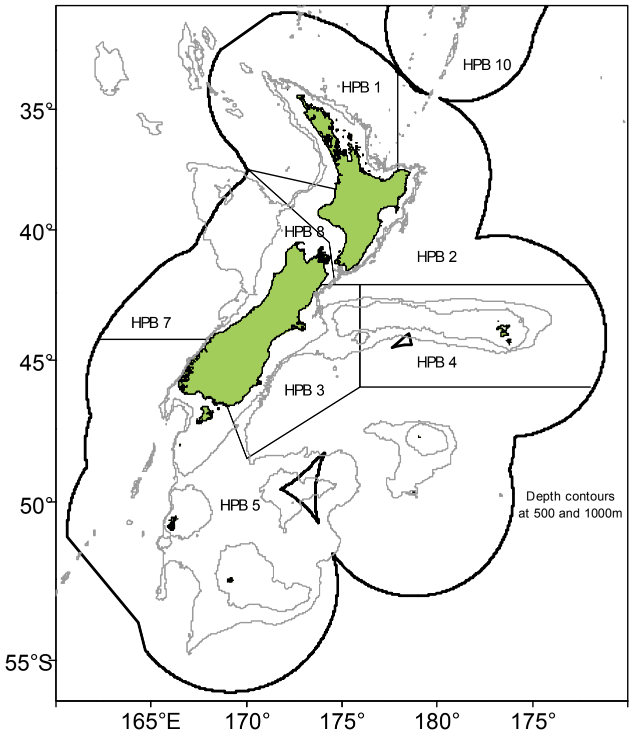


Figure 11. Häpuku/Bass (HPB) quota management areas.

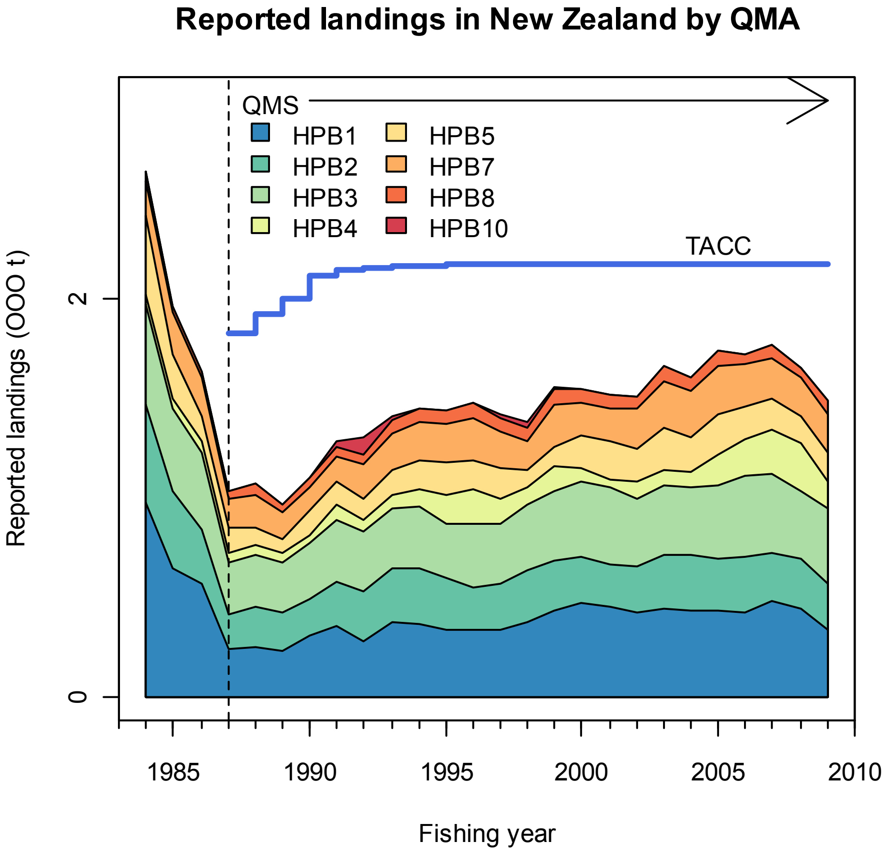


Figure 12. Reported landings of häpuku/bass (HPB) for each Fishstock and the overall TACC from 1984 through to 2009.

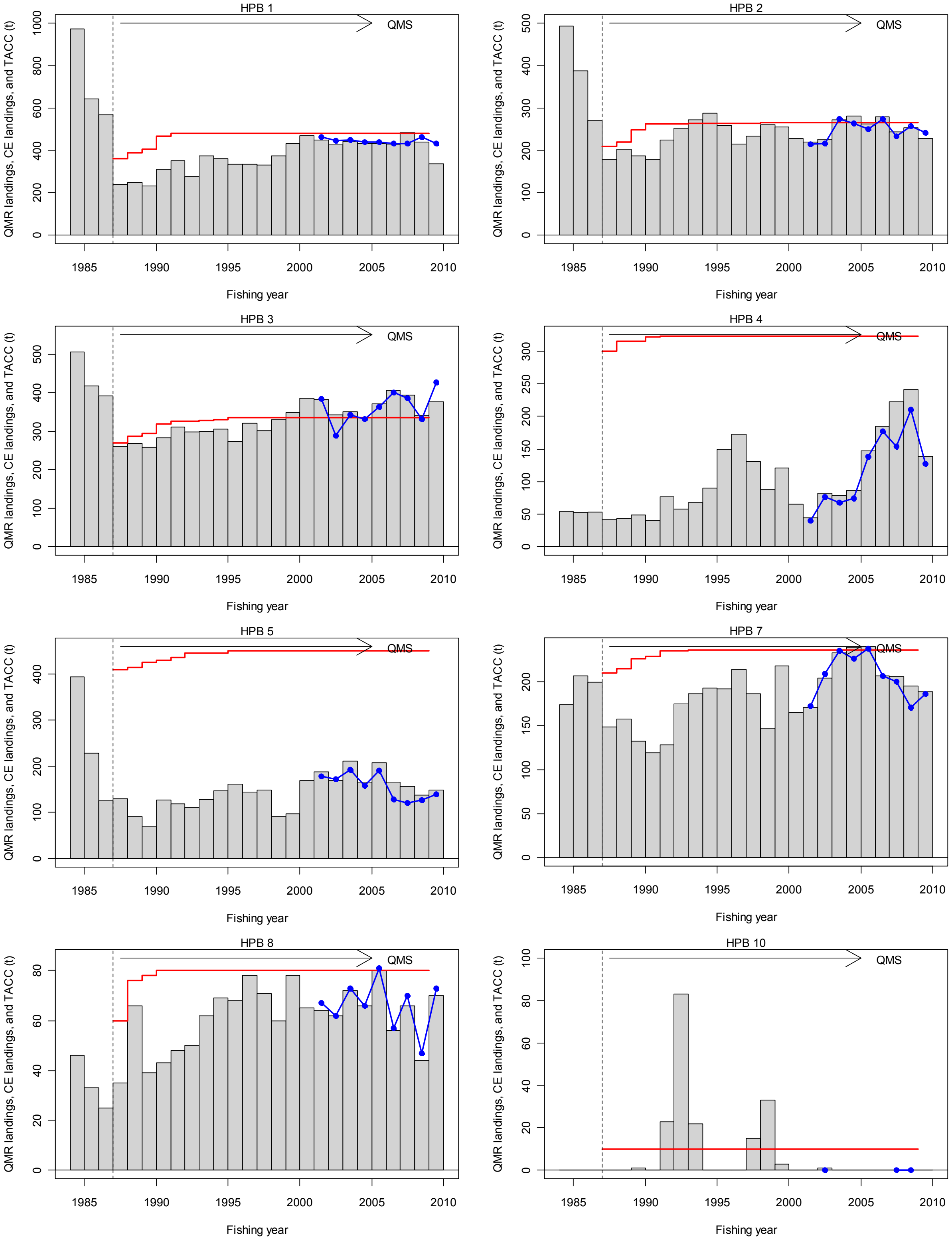


Figure 13. Quota Management Report landings (grey bars) for each HPB fishstock, the TACC for that stock (red line) and the raw, ungroomed reported landings for each fishstock (blue line) from 1984 to 2009. The black line indicates when the QMS began (at the vertical dashed line).

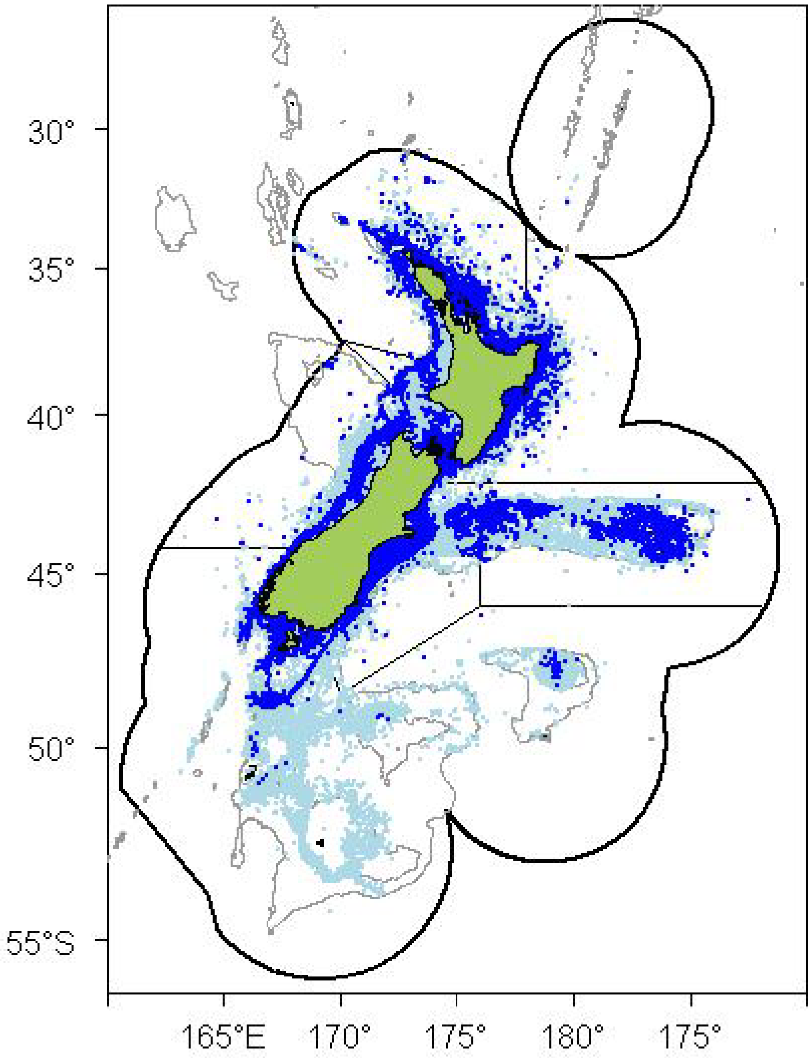


Figure 14. Locations of all fishing events from trips landing HPB (light blue dots) but with no HPB estimated catch, and locations of fishing events where HPB catch was estimated (dark blue dots), since 1989. Data are from the catch effort database with position reporting from TCEPR, TCER, LTCER, and NCELR forms.

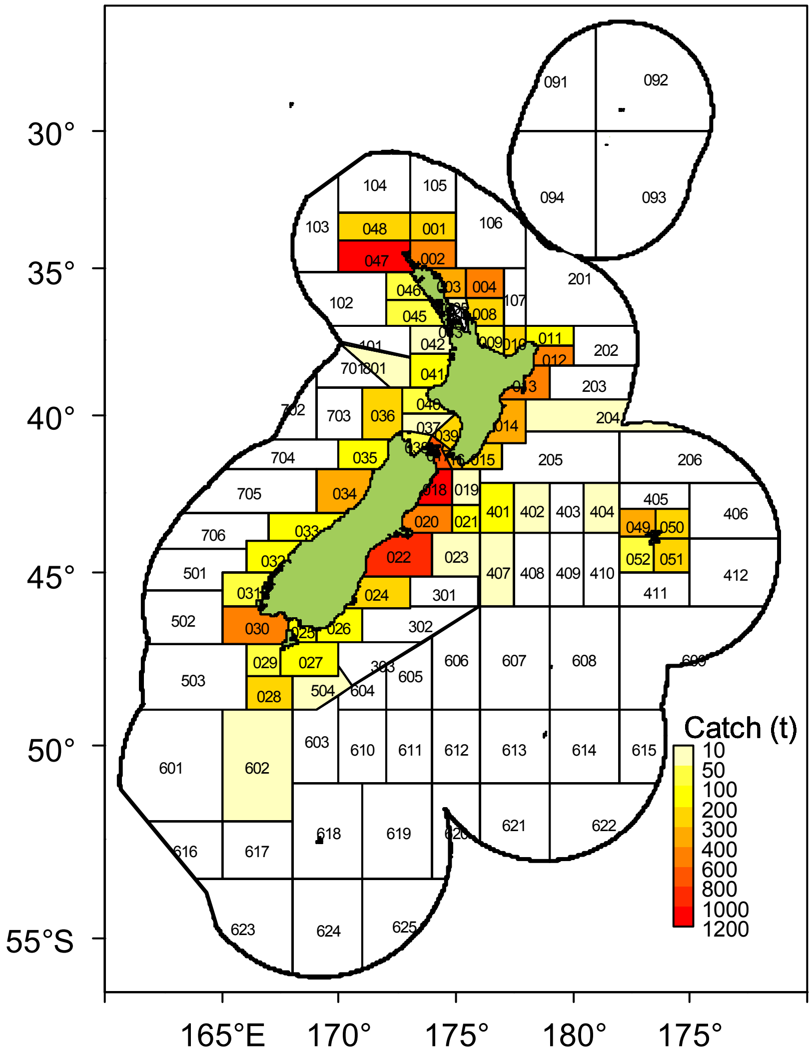


Figure 15. Total HPB landed catch from the catch effort database (2001-2009) pooled by statistical area.

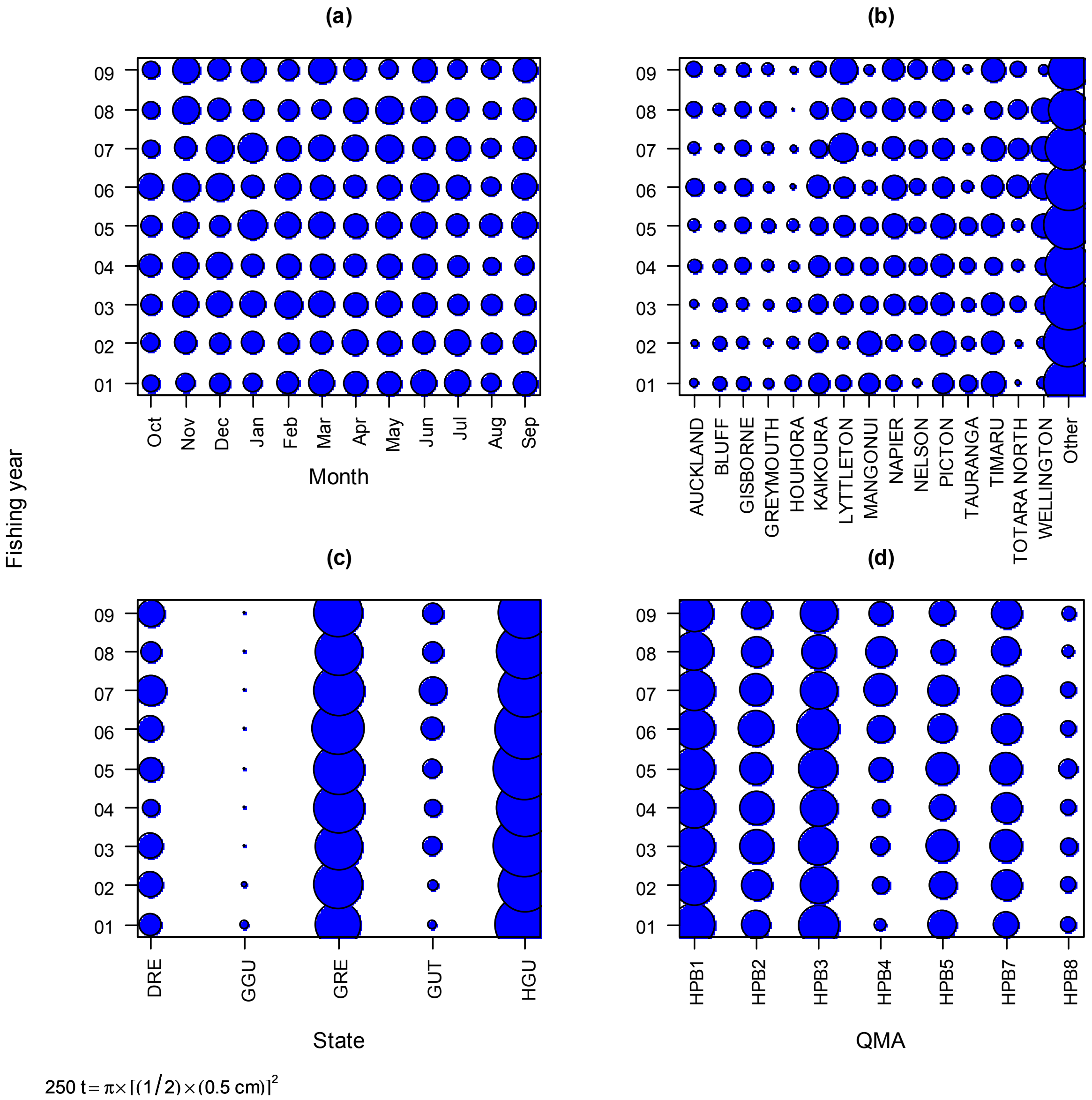


Figure 16. Bubble plots of the total HPB landed catch (all QMAs combined) by fishing year (2001-2009) separated by month, port (top 15), landed state, and QMA. Bubble areas are proportional to the landed catch in a given year, with zero represented as a dot.

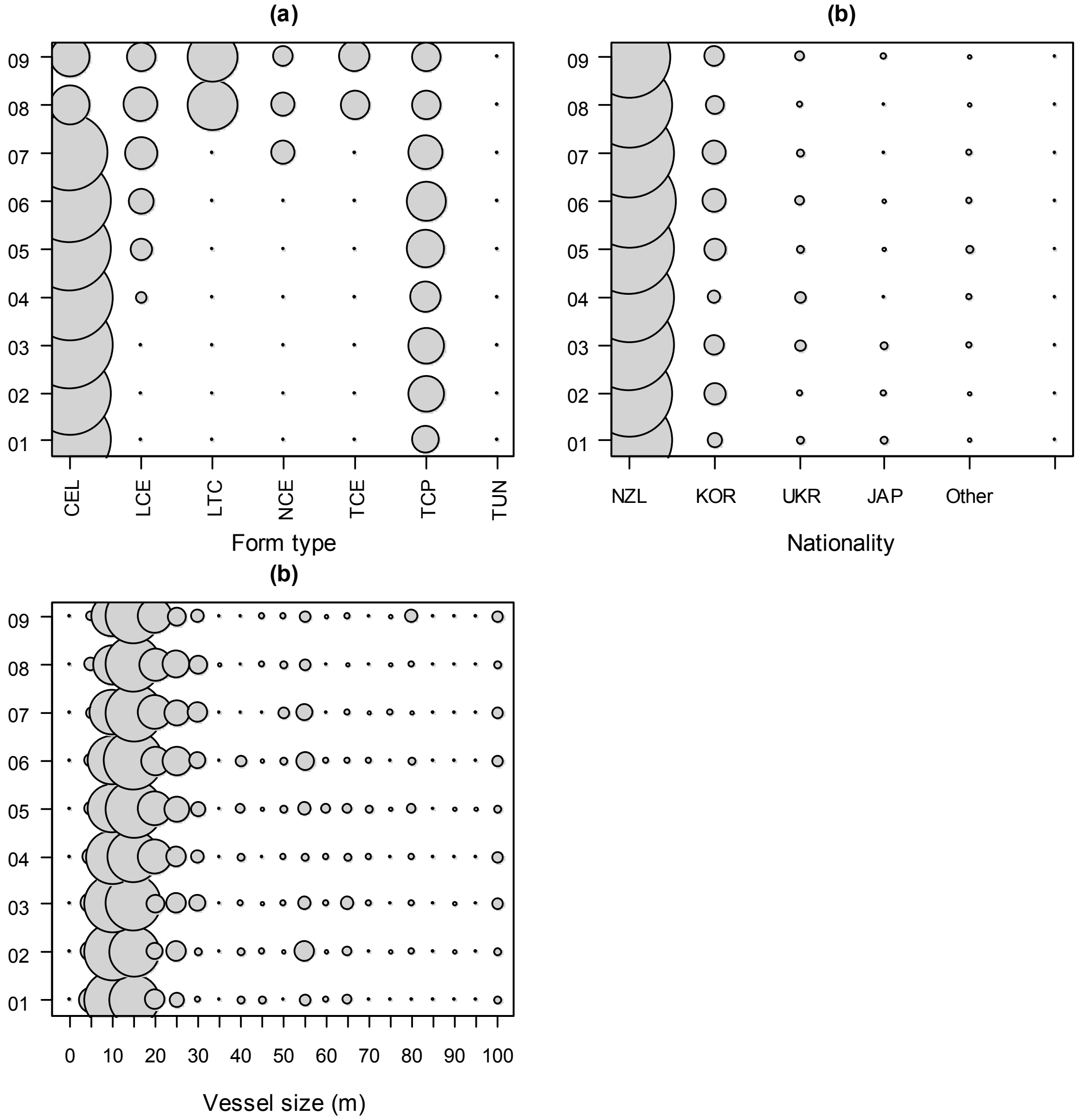


Figure 17. Bubble plots of the distribution of landed HPB catch each year (2001-2009) separated by form type used, vessel nationality, and vessel overall length. Bubble areas are proportional to the landed catch in a given year.

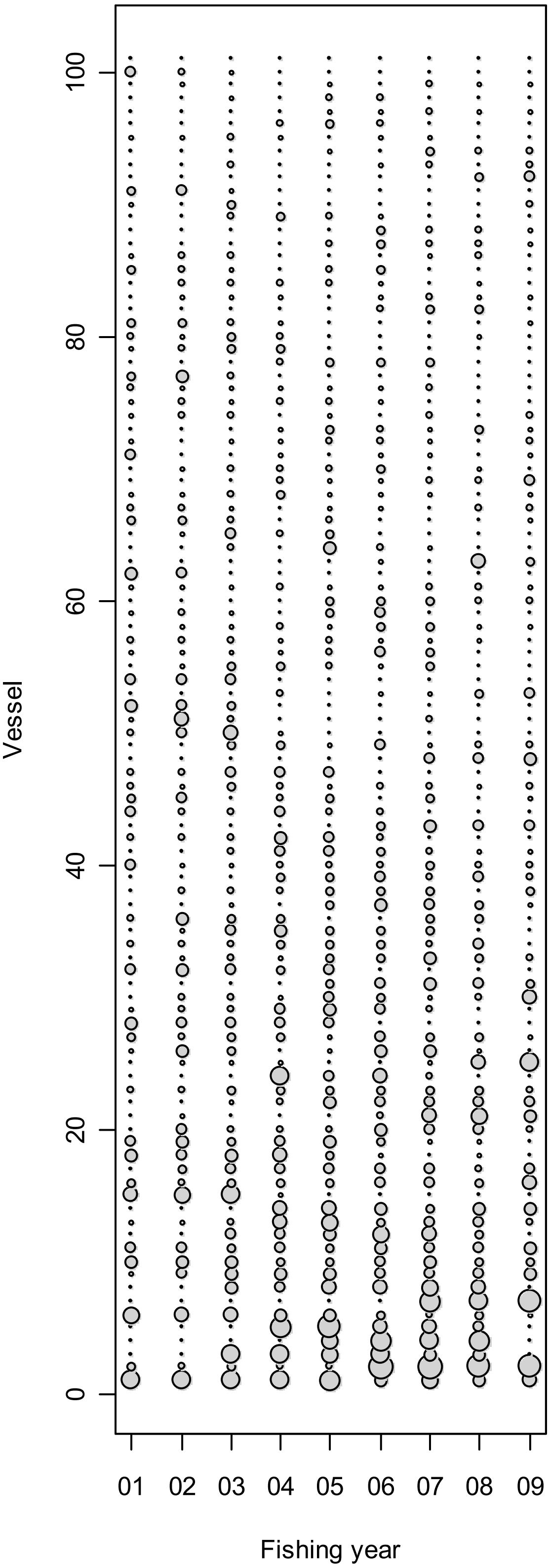


Figure 18. Bubble plot of the distribution of landed HPB catch for each year (2001-2009) for the top 100 individual vessels, ranked by total overall catch.

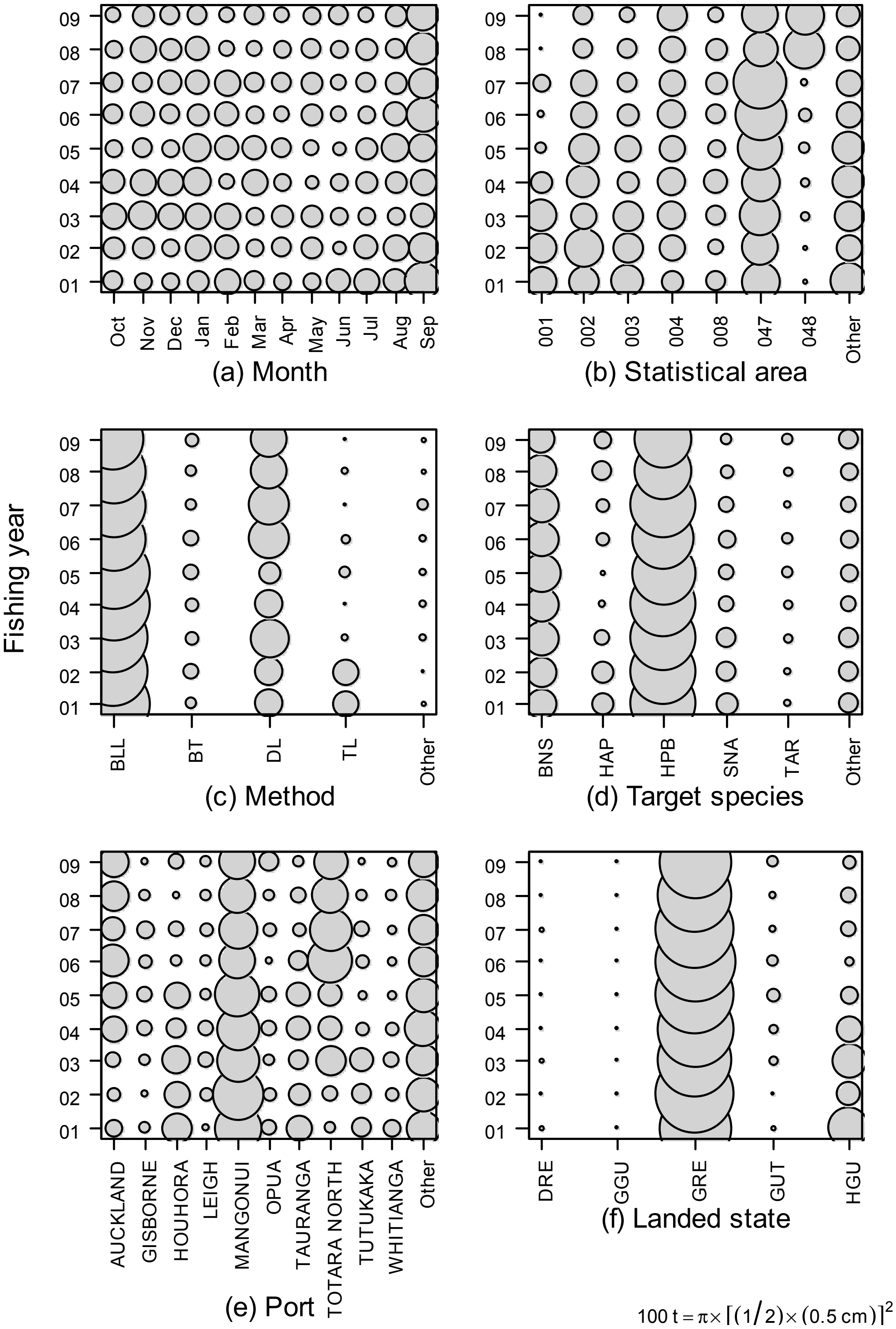
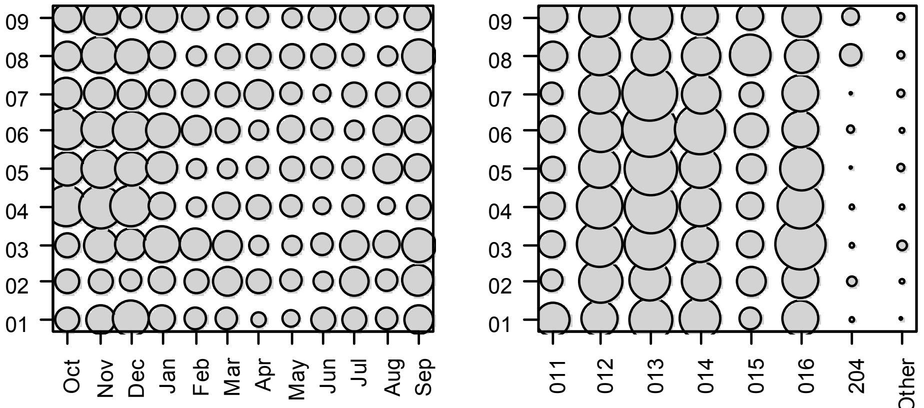
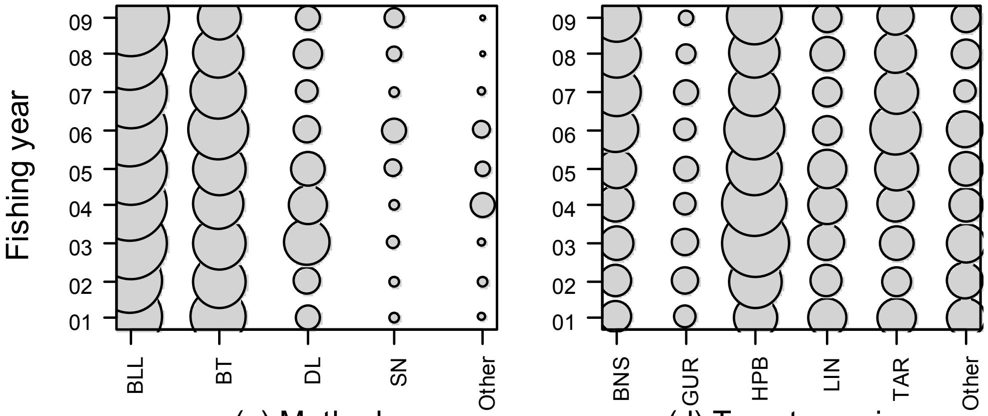


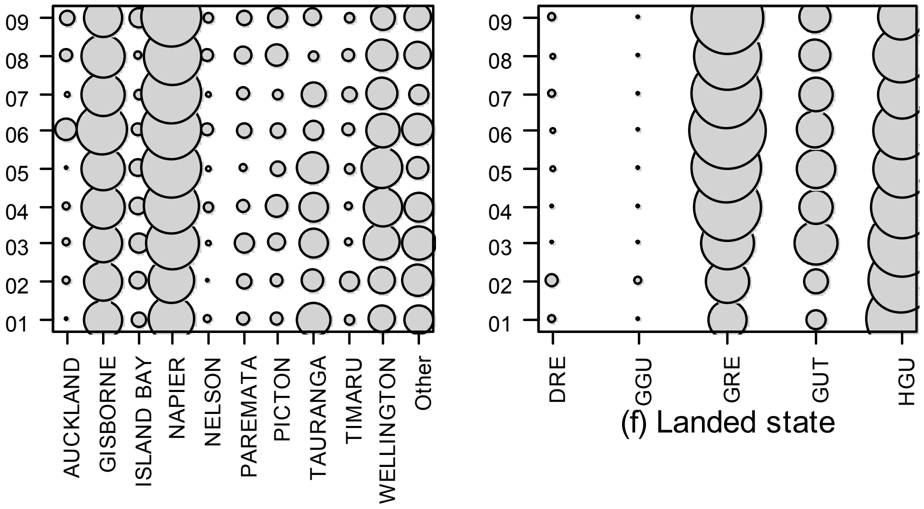
Figure 19. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 1, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.



(a) Month (b) Statistical area



(c) Method (d) Target species

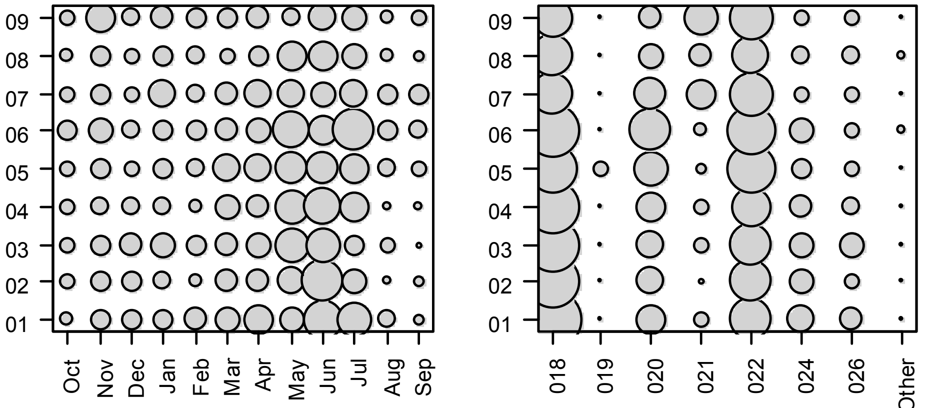


(f) Landed state

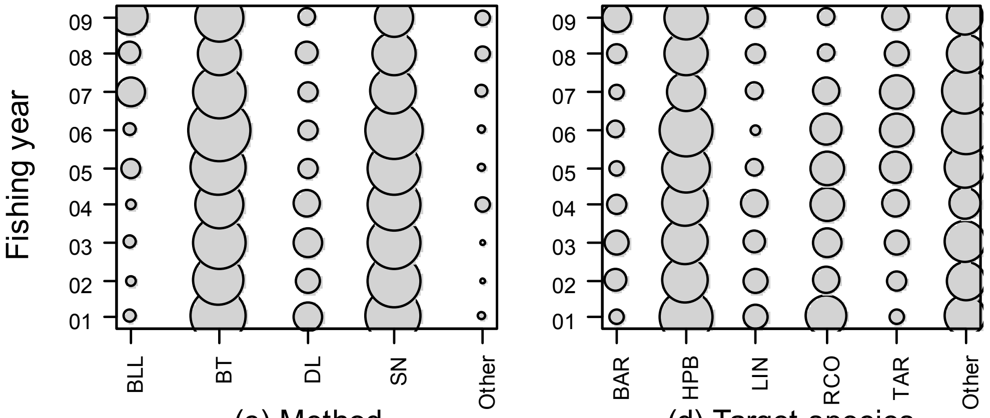
(e) Port

$50\ t = \pi \times [(1/2) \times (0.5\ cm)]^2$

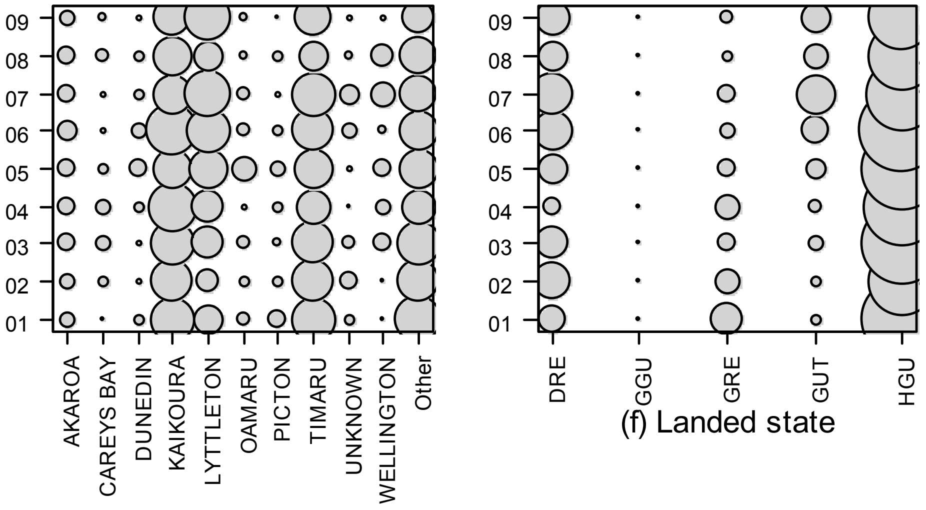
Figure 20. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 2, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.



(a) Month (b) Statistical area



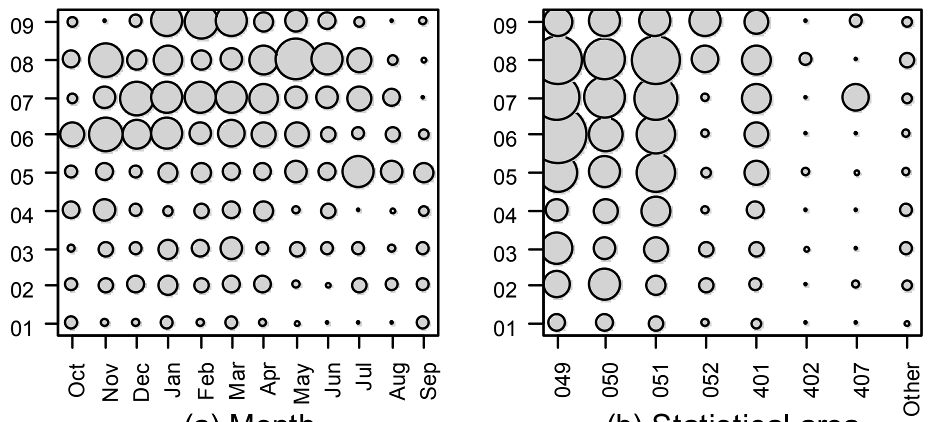
(c) Method (d) Target species



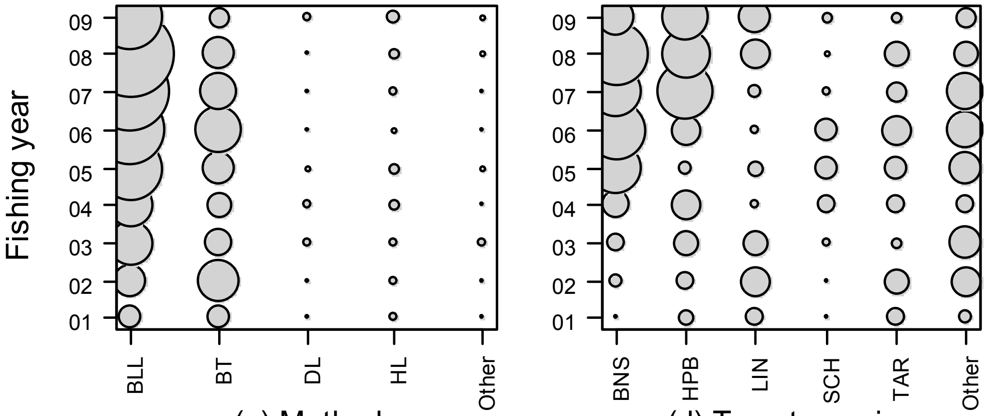
(e) Port (f) Landed state

$100\ \text{t} = \pi \times [(1/2) \times (0.5\ \text{cm})]^2$

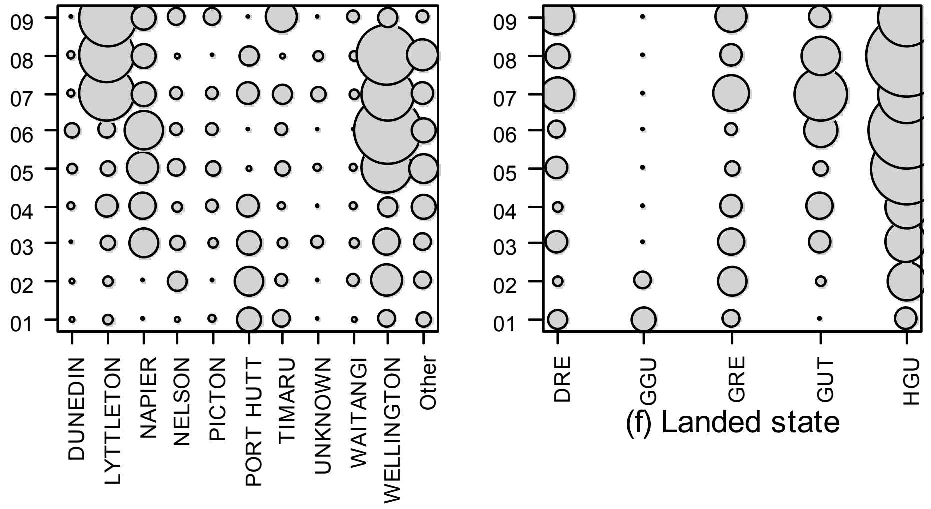
Figure 21. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 3, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.



(a) Month (b) Statistical area



(c) Method (d) Target species

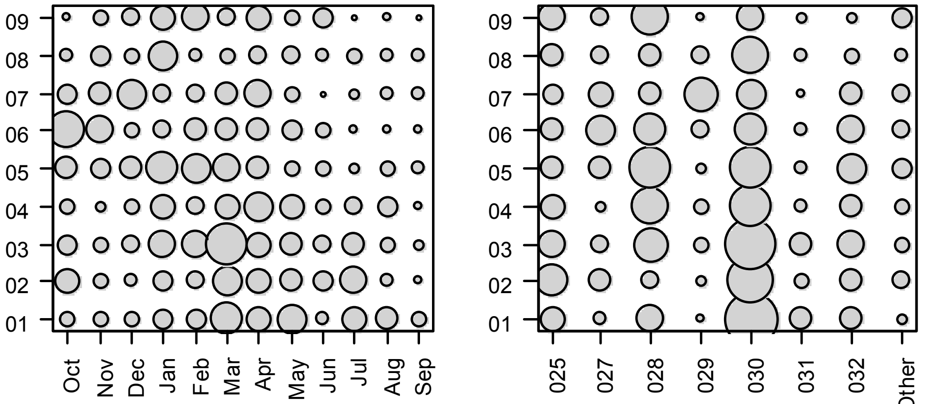


(f) Landed state

(e) Port

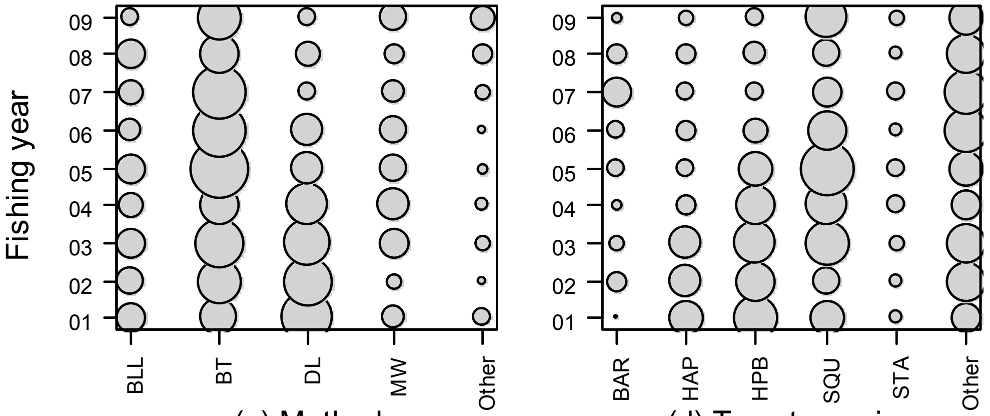
$50\ \mathrm{t} = \pi \times [(1/2) \times (0.5\ \mathrm{cm})]^2$

Figure 22. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 4, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.



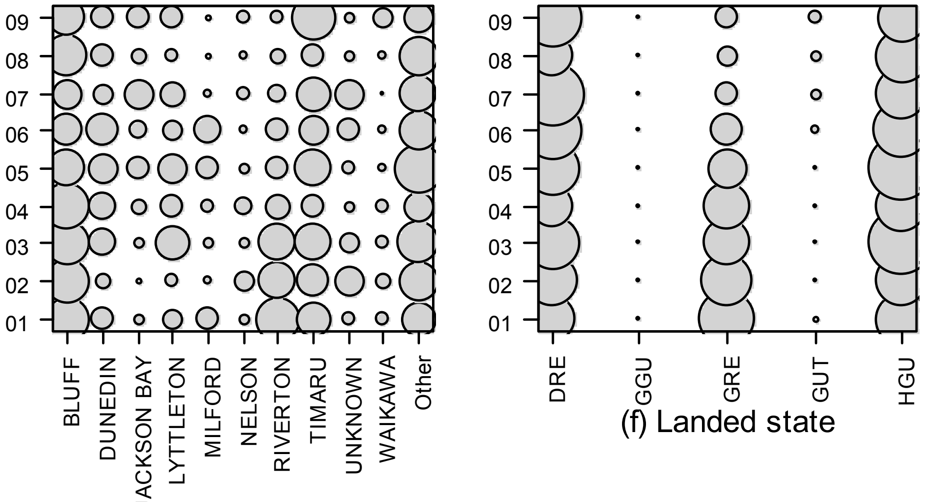
(a) Month

(b) Statistical area



(c) Method

(d) Target species

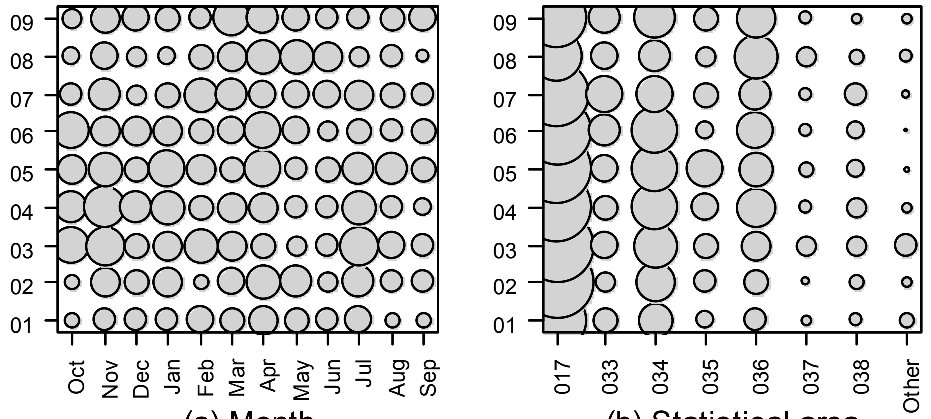


(f) Landed state

(e) Port

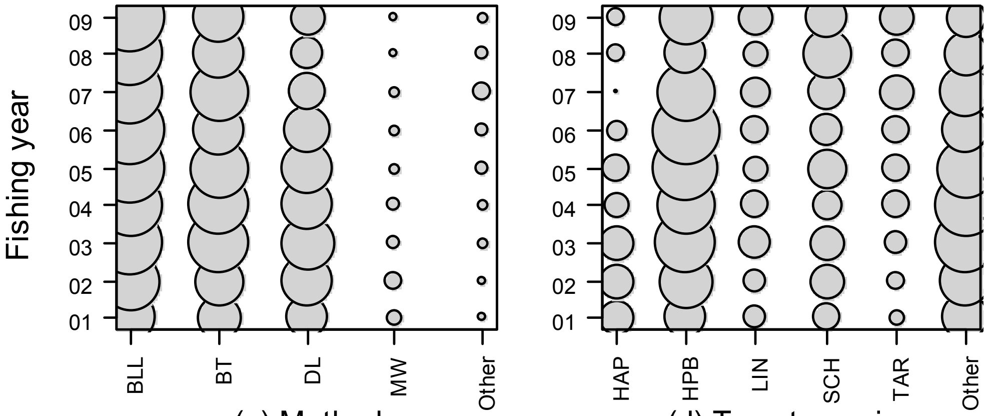
$60\,\text{t} = \pi \times [(1/2) \times (0.5\,\text{cm})]^2$

Figure 23. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 5, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.



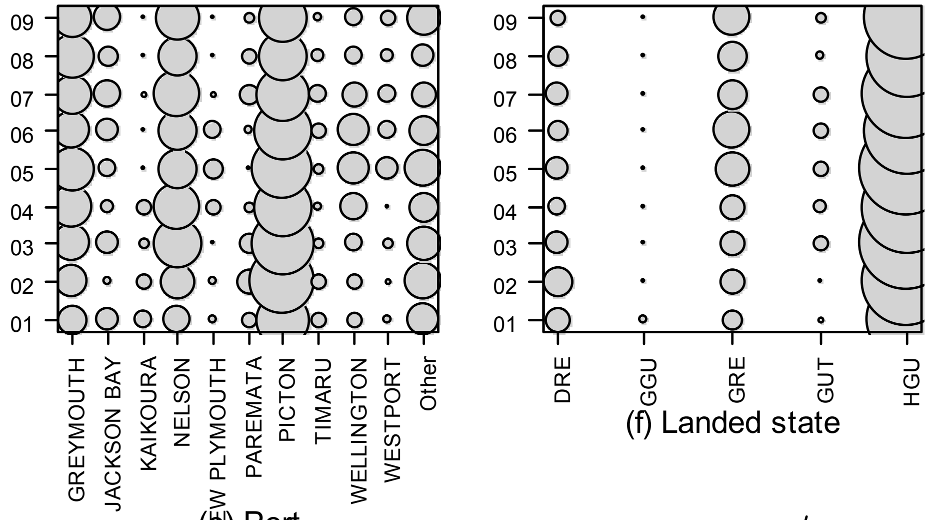
(a) Month

(b) Statistical area



(c) Method

(d) Target species



(e) Port

(f) Landed state

$40\,t = \pi \times [(1/2) \times (0.5\,cm)]^2$

Figure 24. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 7, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.

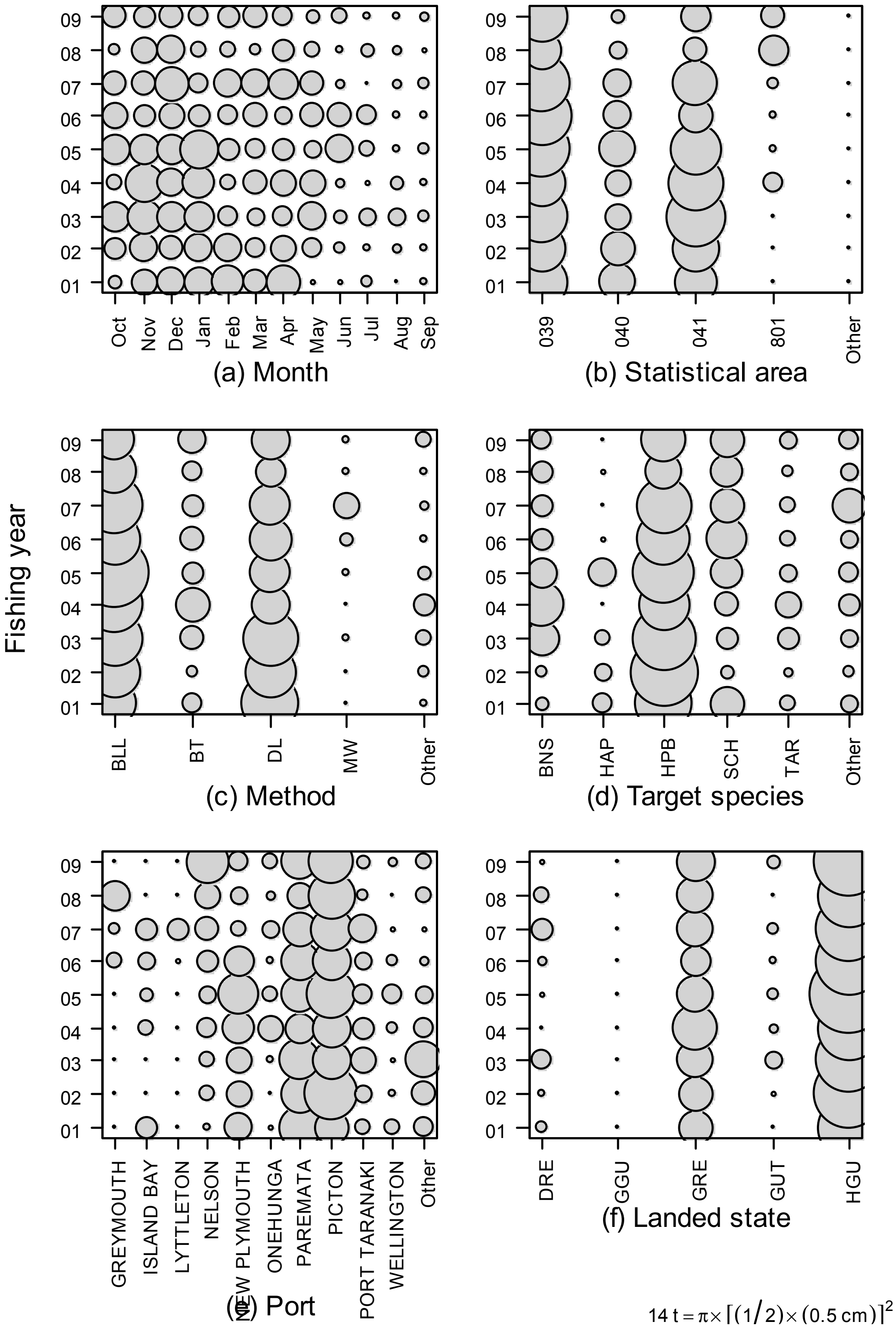


Figure 25. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for HPB 8, separated by month, statistical area, fishing method, target species, port of landing, and landed state. Bubble areas are proportional to the landed catch in a given year.

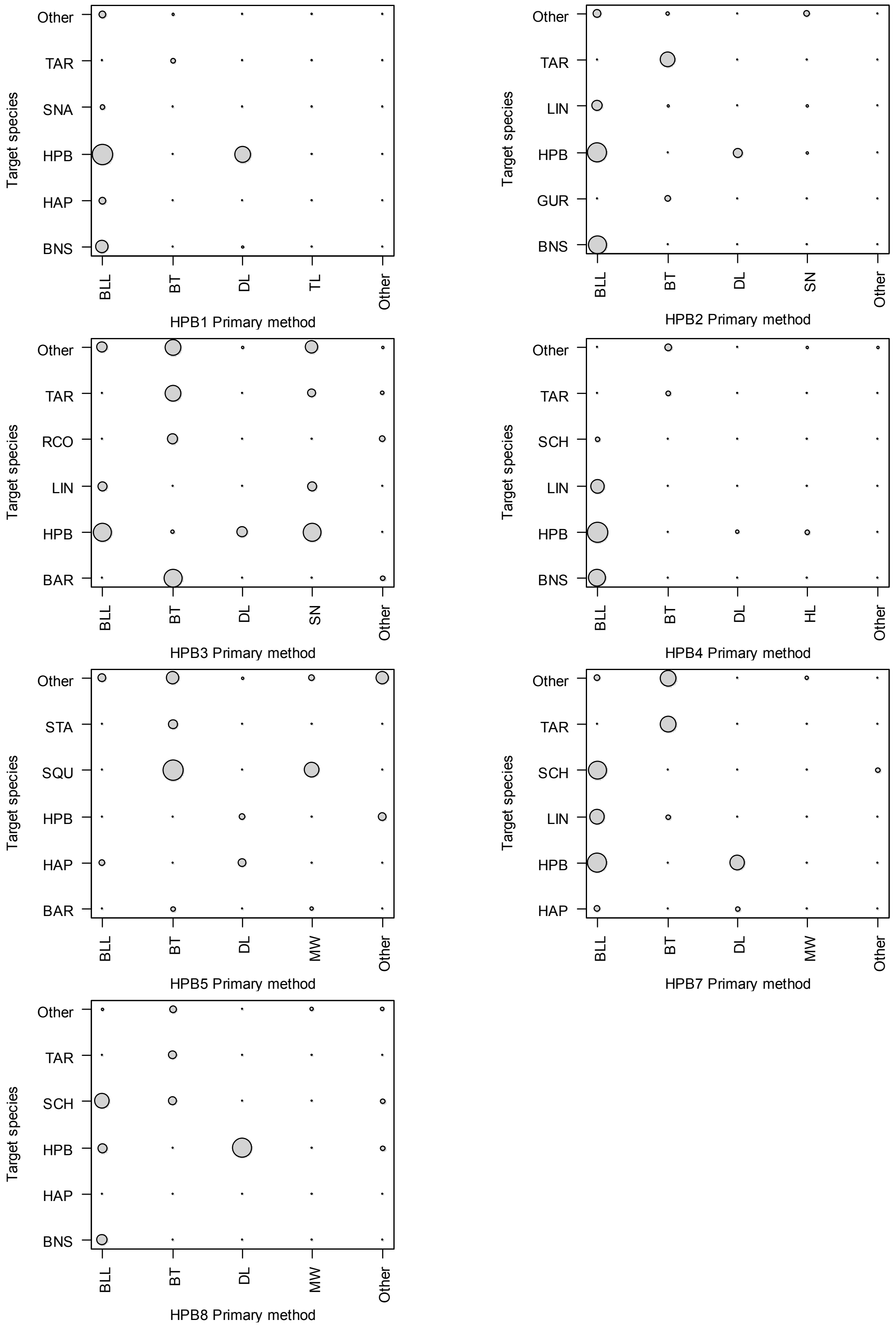
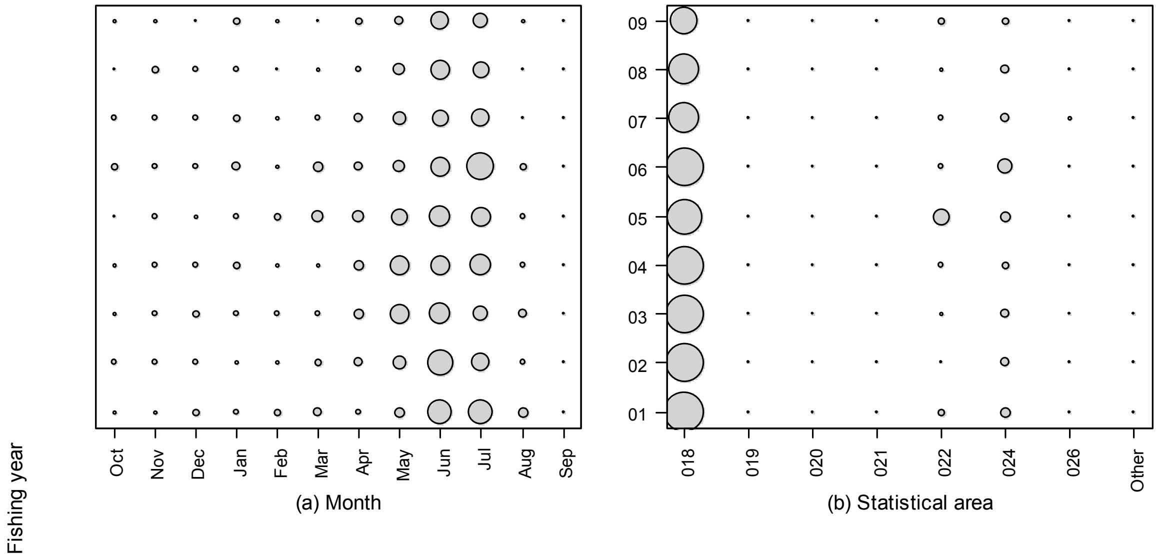
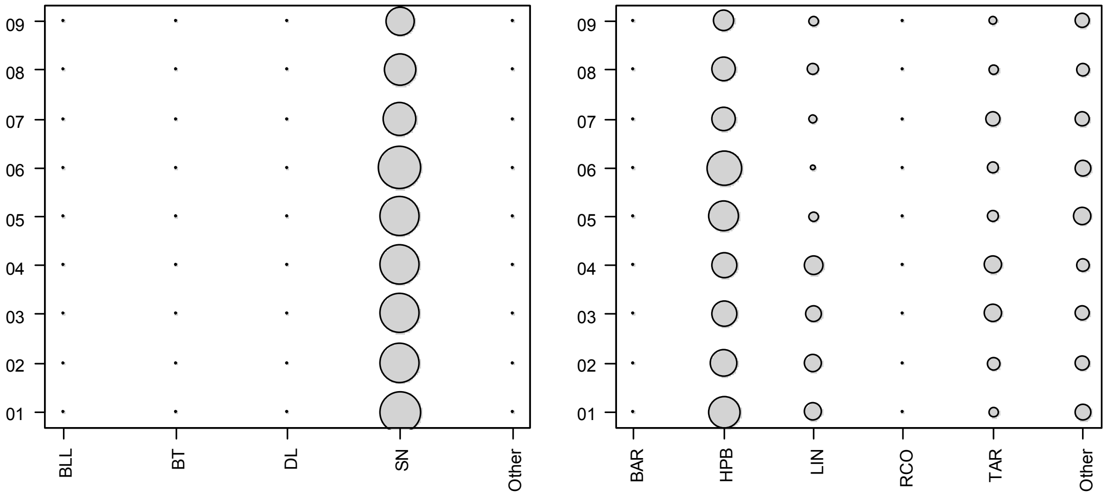


Figure 26. Bubble plots of the distribution of landed catch from 2009 for each target species separated by fishing method in each QMA.



(a) Month

(b) Statistical area



(c) Method

(d) Target species

$80\,t = \pi \times [(1/2) \times (0.5\,cm)]^2$

Figure 27. Bubble plots of the distribution of landed HPB catch each year (2001-2009) for the set net target fishery in HPB 3, separated by month, statistical area, fishing method, and target species. Bubble areas are proportional to the landed catch in a given year.