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Length and age structure of commercial landings of red gurnard (*Chelidonichthys kumu*) in GUR 2 in 2009–10

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Length and age composition of the GUR 2 commercial bottom trawl catch were estimated for the 2009–2010 fishing year. No formal strata were included in the sampling design (temporal or spatial), although sampling was spread throughout the year and among licensed fish receivers to adequately represent the total trawl landings. Forty samples of 50 fish each were targeted and achieved. Sampling took place mainly in Napier and Gisborne, with additional sampling in Auckland of fish trucked from other Napier landings.

The sampled landings matched well the patterns of commercial landings with respect to depth fished, month, statistical area, and target species. Length samples were scaled to the total GUR 2 bottom trawl landed catch. Length compositions were unimodal, with females larger than males (both in mean size and maximum size), and with an even sex ratio (in contrast with the GUR 1 catch which has a sex ratio skewed toward females). No strong difference in length composition was noted between trips fishing north and south of the Mahia Peninsula.

Otoliths were collected using a random age frequency approach. Ages were determined using baked and embedded otoliths and final age was assigned using the forced margin method following Ministry of Fisheries ageing protocols. A total of 1078 otoliths were aged and final agreed ages determined through a conferring process. The maximum age encountered was 14, and the total mean weighted coefficient of variation for the landed catch age composition was 15%. No difference in age composition was noted between males and females. However, the proportion of young fish (1–2 year olds), increased between spring-summer and autumn-winter samples, indicating that fast growing young fish are progressively selected into the fishery during the year. This will have implications for future catch sampling designs and also for any stratification structure chosen for assessment purposes.

Age and growth data collected using the random age frequency method did not provide adequate samples of large or small fish, influencing the fit of growth functions. In addition, maturity data were not representative with many resting fish throughout the year resulting in poor fits for age/size-at-maturity ogives and limiting the use of these samples for additional stock productivity analyses. However, length and age compositions were very similar to those generated by previous studies in 2003–2005, in the 1990’s, and in 1970, suggesting that the age composition of the catch has been stable for many years.

Although uncertain, estimates of F from this study were approximately equal to the estimate of natural mortality. This, combined with a relatively constant catch history over the last few decades, suggest that GUR 2 was not over-exploited in 2010.

Given the observed variation within the age composition throughout the year, the number of landings and the number of otoliths sampled per landing were optimized for potential future sampling designs. The simulation suggested that coefficient of variation estimates near 20% can be generated by sampling only 20–30 landings if a simple spring-summer and autumn-winter stratification scheme is used, but more samples would be needed if more temporal resolution is desired.

1. INTRODUCTION

Red gurnard (*Chelidonichthys kumu*) is a demersal finfish species widely distributed within the shallow coastal waters of the New Zealand fishery zone. It is a major bycatch of most inshore trawl fisheries including fisheries for red cod in the southern regions, tarakihi and snapper off the eastern North Island, and flatfish on the west coast of the South Island and in Tasman Bay.

There is no current stock assessment for GUR 2. A standardised catch per unit effort (CPUE) analysis by Kendrick (2009) showed a relatively flat CPUE history and the total allowable commercial catch (TACC) allocation has not changed since 1989.

Catch sampling last took place during the 2003–04 and 2004–05 fishing years (Phillips et al. 2005, Horn et al. 2006). Catches were dominated by strong year classes of 2–4 year old fish, with no apparent year class progression between 2002–03 and 2004–05. The 2004–05 programme sampled 12 landings from a planned total of 15, achieving a mean weighted coefficient of variation (MWCV) of 15%. However, these samples represented only 9.5% of the total GUR 2 landings, and were not considered to be representative of any temporal patterns in the fishery (Horn et al. 2006).

The purpose of this project was to develop a catch sampling plan for GUR 2 for the 2009–10 fishing year, determine the age composition of the GUR 2 catch, and use these data to develop an optimal sample size for future GUR 2 catch sampling projects.

Specific objectives:

1. Characterise the GUR 2 fishery and design a catch sampling programme to sample GUR 2 catches taken by the bottom trawl method.

2. To conduct representative sampling and determine the length, sex, and age composition of the bottom trawl catch of red gurnard (*Chelidonichthys kumu*) in GUR 2 during the 2009/10 fishing year. The target coefficient of variation (c.v.) for the catch-at-age is 30% (mean weighted c.v. across all age classes) combined across sexes.

3. To explore the time series of catch sampling data, in particular, for any significant changes in the length and age composition of commercial catches.

4. To develop a cost-effective catch-at-age sampling strategy for GUR 2.

1.1 Stock area

GUR 2 encompasses the east coast of the North Island from Cook Strait to East Cape and is comprised of statistical areas 011–016 (and parts of 018 and 019), and 201–206 (Figure 1).

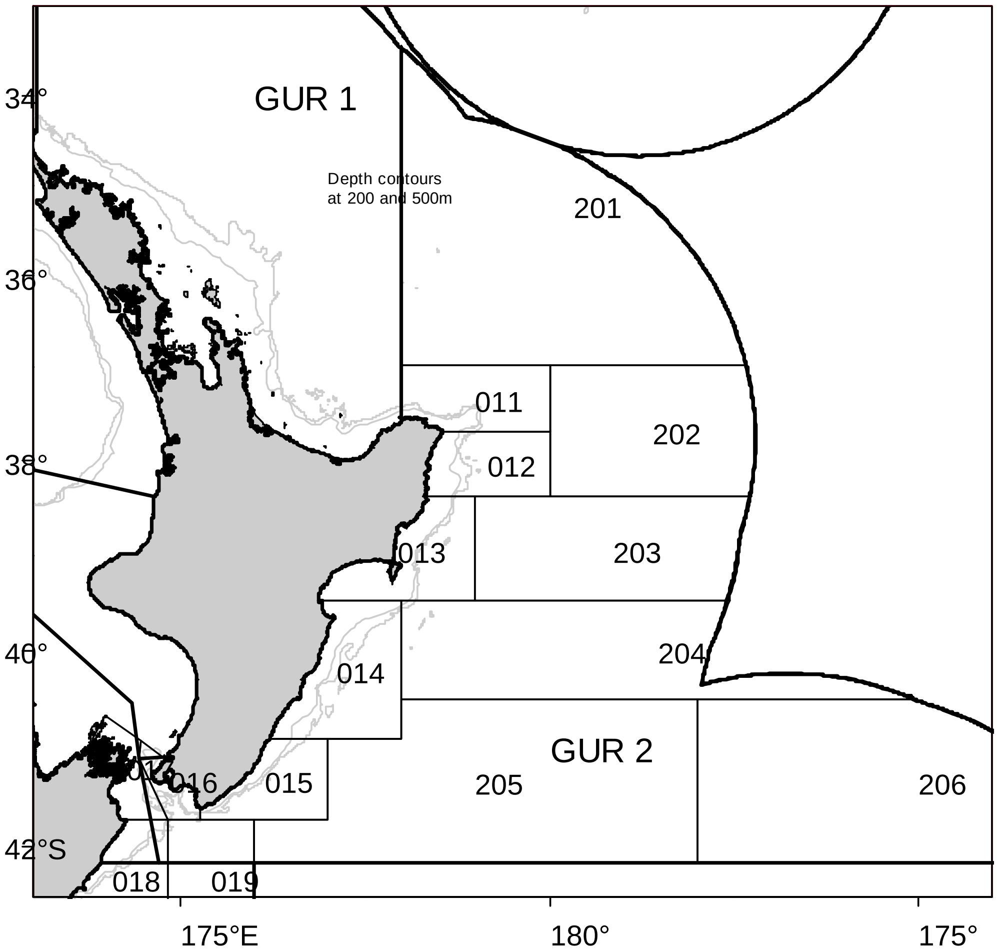

Figure 1: Location of statistical areas within the GUR 2 fishery management area. The 200 m and 500 m depth contours are shown as light gray lines.

1.2 Commercial fisheries

The current TACC for red gurnard is almost 5000 t, of which GUR 2 is allocated 725 t (Ministry of Fisheries 2010) (Figure 2). There have been significant landings of GUR 2 since 1984 with some of the highest landings early in the time series. GUR 2 exceeded the TACC for the first time in 2010.

In this report, fishing year is referred to by the year in which the 12-month fishing year ends; the October 2009–September 2010 period is referred to as the 2010 fishing year.

1.3 Recreational fisheries

In 2004, the Marine Recreational Fisheries Technical Working Group reviewed the harvest estimates of these surveys and concluded that the 1993/94 and 1996 estimates were unreliable due to a methodological error. While the same error did not apply to the 1999/2000 and

2000/01 surveys, it was considered the estimates may still be very inaccurate. The 2000–2001 estimates of recreational harvest of GUR 2 reported a range of 80–127 t, (Boyd & Reilly 2002).

1.4 Maori customary fisheries

No quantitative information on the level of customary non-commercial fishing is available.

1.5 Illegal and misreported catch

No quantitative information on the level of illegal tarakihi catch is available.

1.6 Other sources of mortality

No information is available.

2. COMMERCIAL FISHERY CHARACTERISATION

The following brief fishery characterisation was conducted to inform the development of a catch sampling programme and hence characteristics unrelated to the spatial or temporal stratification of market samples are not described. Data grooming and summary procedures were conducted following those in Parker and Fu (2011). A full characterisation of fishery behaviour can be found in Kendrick & Walker (2004) and Kendrick (2009).

2.1 Historical catches

Total catch of GUR 2 has been stable between about 500 and 600 t for the past decade, and below the TACC for the history of the fishery until 2010, when it was exceeded by 106 t or 15%, (Figure 2).

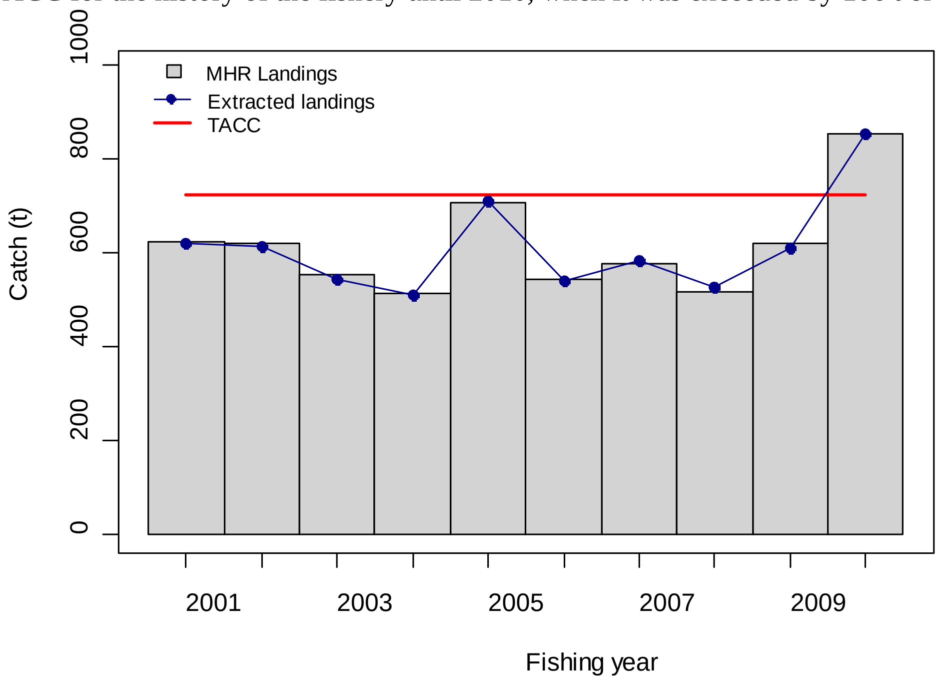

Figure 2: Total commercial catch, Monthly Harvest Return (MHR), total reported landings, and total allowable commercial catch of GUR 2 (2001–2010).

2.2 Main fishing methods

Red gurnard was landed almost exclusively by bottom trawl (96% during the last decade), with minor catches from Danish seine, set net, and bottom longline (Table 1). The proportion of catch by bottom trawl has been stable during this period also. Therefore, the fishery characterisation was conducted on bottom trawl catch only.

Table 1. Total landed catch (t) by fishing method from 2001 to 2010. BT, bottom trawl; DS, Danish seine; SN, set net; BLL, bottom longline; T, troll.

Fishing year	BT	DS	SN	BLL	T	Other	Total
2001	528	74	4	3	1	0	610
2002	541	63	4	1	0	0	609
2003	530	2	3	1	0	0	536
2004	501	1	2	1	0	0	505
2005	696	0	7	0	0	0	703
2006	535	0	2	0	0	0	537
2007	566	5	2	0	0	0	573
2008	500	11	3	0	0	0	514
2009	585	0	5	1	0	0	591
2010	806	22	3	0	0	0	831
Total	5 788	178	35	7	1	0	6 009

There was little seasonal trend in catch by target species, though the maximum overall landings tended to occur in the spring months (Figure 3a). The fine-scale monthly landings pattern for GUR target tows was variable among years, which hinders the ability to predict monthly landing proportions for catch sampling programmes. Spatially, most catch consistently occurred in statistical area 013, off Mahia Peninsula, with decreasing catch in statistical areas to the north and south (Figure 3b). A similar proportion of non-target catch occurred in each statistical area.

The pattern in fishing was consistent across port, where both Napier and Gisborne landings stem from fishing in statistical area 013, but with more landings from area 014 in Napier (Figure 4c). Trawl Catch Effort Processing Return forms (TCEPR) are used by vessels greater than 28 m in length, and Catch Effort Landing Return forms (CELR) used by smaller vessels. Since 2008, 6–28 m vessels have been required to use Trawl Catch Effort Return forms (TCER), which in addition to requiring tow-level location and effort data, also require listing the top eight species caught by greenweight. Therefore, most CELR vessels now report catch with TCER forms. The landings summaries are segregated by these two groups of vessels. The primary port for GUR 2 landings is Napier, with Gisborne a distant second, and this trend has been consistent through time (Figure 4a). Other ports contribute a very minor proportion to the landings. The fishery occurs year round, with a slight emphasis on spring–summer landings (Figure 4b). In all cases, TCEPR landings contribute about 20% to the total landings and the majority of the landings are by CELR/TCER vessels.

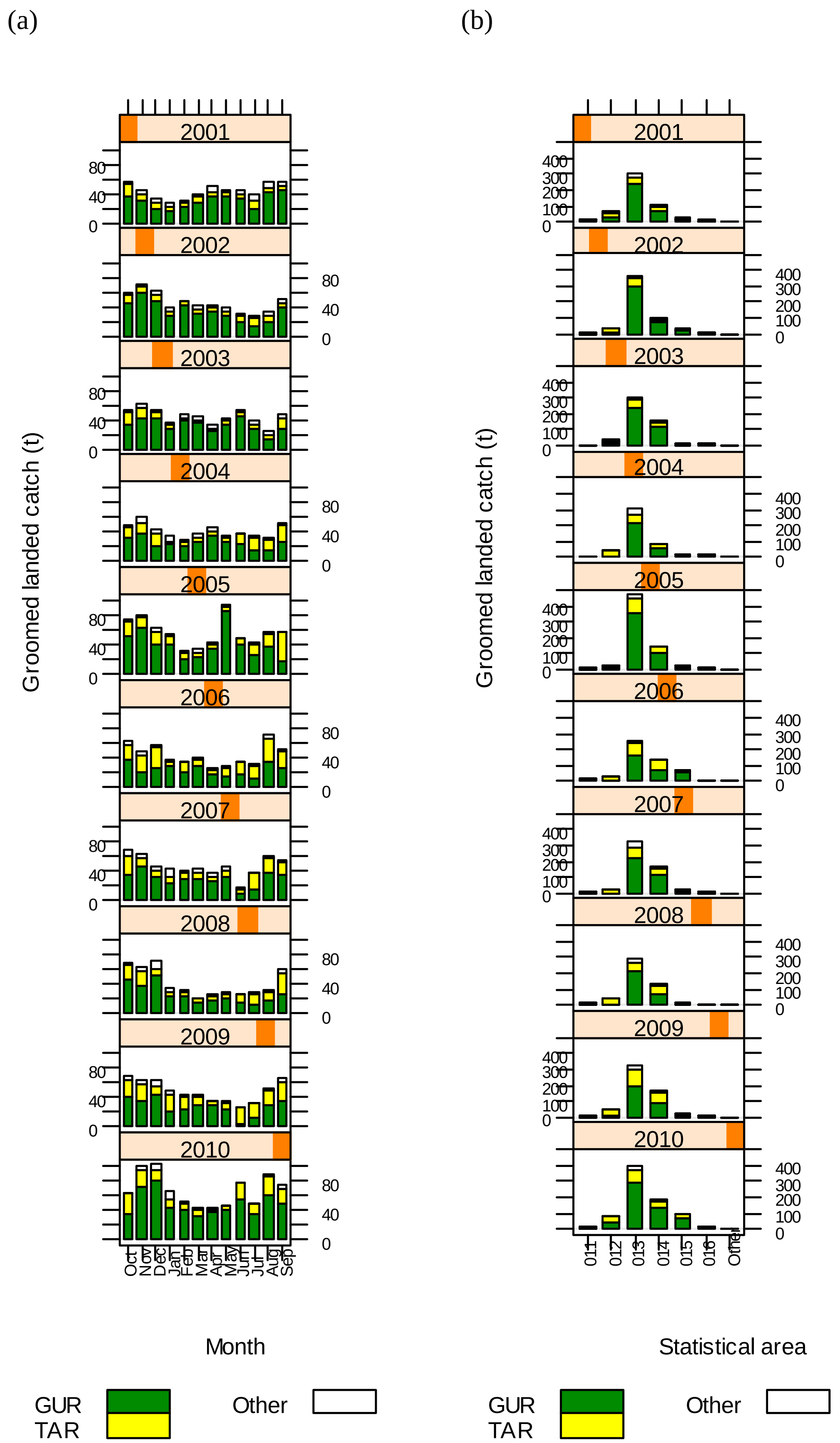

Figure 3: Total GUR 2 landings by (a) month and year and (b) statistical area and year, 2001–2010, showing the proportion of catch landed from tows targeting GUR (dark green), TAR (light yellow), or other species (white).

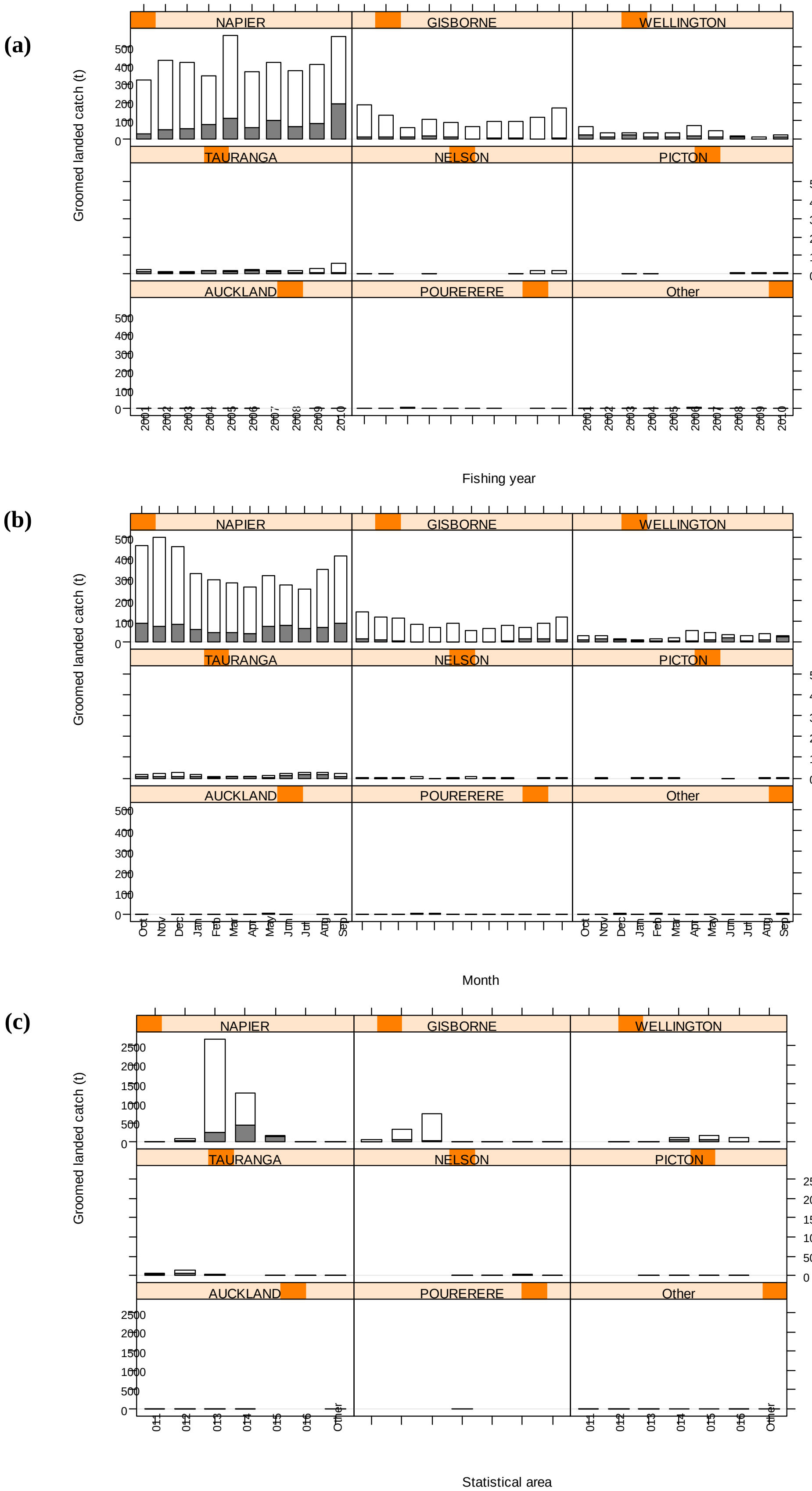

Figure 4: **Distribution of landed catch of GUR 2 by major port and (a) year, (b) month, and (c) statistical area, 2001-2010. Total landed catch is split by reporting form type; either TCEPR (gray) or other (CELR / TCER).**

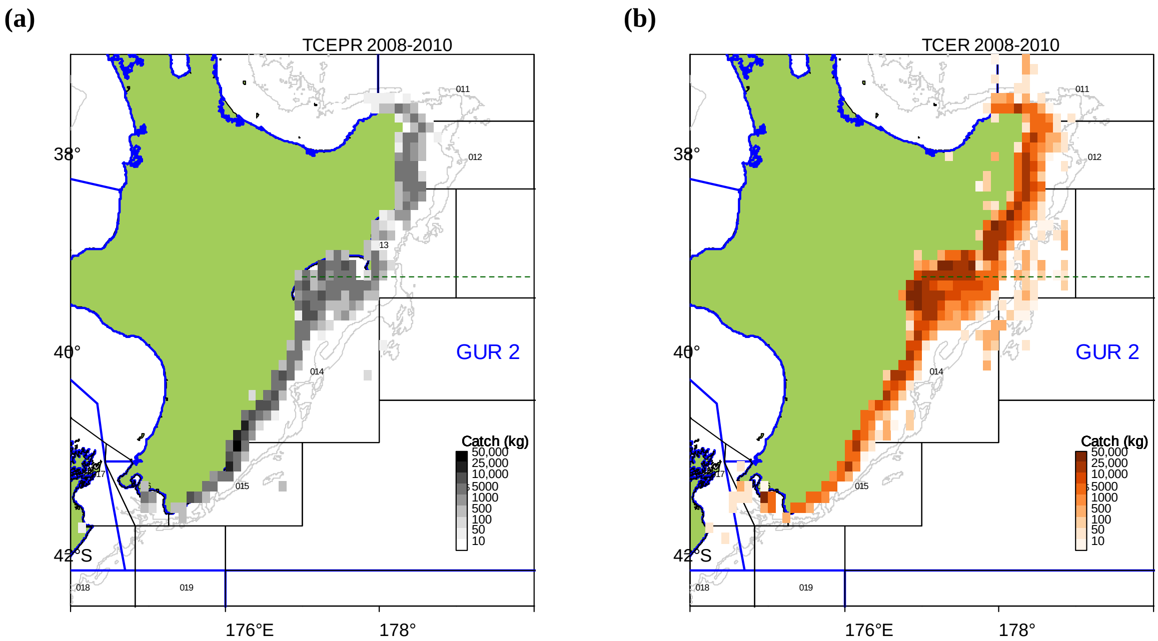

Figure 5: Total fine scale spatial distribution of GUR 2 catch (in 0.1 degree blocks) within each statistical area, 2008–2010, for vessels using (a) TCEPR forms or (b) TCER forms.

With the introduction of the TCER form, the spatial distribution of catch is now available with a much higher spatial resolution than the statistical area data available on the CELR (Figure 5). The TCEPR data show that most catch occurred in shallow coastal waters along the entire east coast of the North Island. Although the majority of the catch comes from Hawkes Bay, some high catches were reported along the Wairarapa coast. TCER data shows the same general pattern, but with additional catches in deeper water. The spatial distribution of catch by different size vessels (6–28 m and above 28 m) does not appear to be different based on these data. Because of new forms, and the known depth distributions of red gurnard, the accuracy of these deep water catches reported by smaller vessels (6–28 m) is questionable and should be checked with grooming algorithms as many could be off by a single degree of longitude (e.g., locations on land too). It appears that latitude errors may also be present in data near East Cape.

Within bottom trawl catch, most red gurnard was caught in targeted tows, although a significant proportion of the annual catch was caught during tarakihi (*Nemadactylus macropterus*, TAR) targeted tows (Figure 6). This aspect of GUR 2 is somewhat different than the general characterisation of gurnard catch as mainly a bycatch species. Minor bycatch of red gurnard occurred in tows targeting snapper (*Pagrus auratus*, SNA) and the flatfish complex (FLA). The proportions vary somewhat by year, but the ranking and overall proportions have remained similar for the past decade.

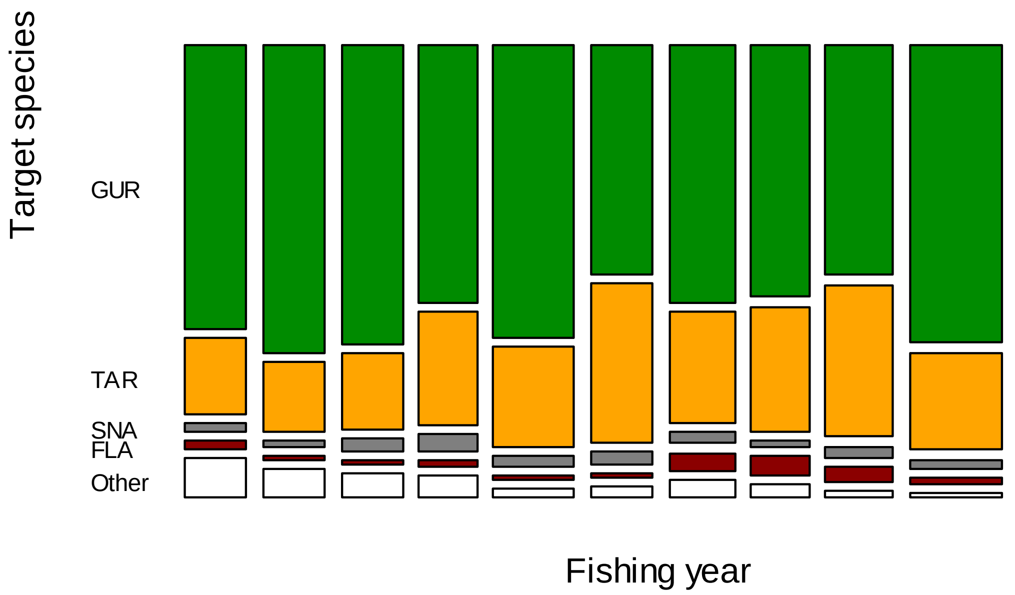

Figure 6: Annual proportion of GUR 2 bottom trawl landings reported by target species, 2001–2010.

3. METHODS

3.1 Sampling design

The purpose of the catch sampling programme was to describe the age composition of the GUR 2 catch in 2010. Although samples obtained through an on-board observer programme would allow the actual location and fishing event associated with each sampled fish to be obtained (along with other sampling data), observer placement on small inshore vessels is not currently feasible, requiring catch sampling to occur on shore at landing from catch aggregated throughout the entire trip.

All sampling was designed, conducted and analysed following recommended practices codified by the Ministry of Fisheries (Science Group 2008). Shore-based samplers ensure that the landings sampled were obtained with only one fishing method. Appropriate landings are identified through voluntary coordination between samplers and processor managers. In some cases, unsorted catch was trucked to secondary processing facilities, which sometimes made obtaining details of the landing difficult for samplers.

3.1.1 Sampling methodology

The working group discussed several options to sample GUR 2 effectively (Northern Inshore Working Group, unpublished documents, October 2009). The sampling plan implemented comprised a single statistical stratum with no spatial or temporal divisions with different levels of sampling, i.e., statistical area, target species, vessel size or gear type (bottom trawl only) were not used as formal strata with a formal allocation of sampling effort. Rather, they were used only to spread sampling effort consciously across those variables to incorporate any variation in catch characteristics associated with them. Statistical areas 016, 017, 018, and 019 were excluded from the sampling design because of potential mixing of stocks within those statistical areas and the low proportion of catches from those areas (see Figure 3). Sampling targeted 2–6 landings per month for 12 months, weighted by by the mean catches observed in 2004–2008. The samples were spread among five main processors in Gisborne and Napier, with about one-third of the samples taken from Napier and Gisborne processors that shipped unsorted catch to Auckland.

A sampling threshold of the landing weight greater than 200 kg was expected to minimize the numbers of landings qualifying for sampling, while maximizing the proportion of the total catch that would comprise sampled trips. Sampling excluded any trips where catch was from more than one quota management area. Fifty fish were processed for each sample using a random age frequency strategy (otoliths collected from all sampled fish) and a total of approximately 1000 otoliths from the expected 2000 fish sampled was planned to be aged . Otoliths were selected for ageing in proportion to the relative weight of each sampled landing, with a minimum of 10 otoliths selected from each landing.

Criteria for selecting landing to sample

1. Landing sampled must be from a single vessel for a single trip using only bottom trawl.
2. Landing weight of GUR 2 must be over 200 kg.
3. Sample frequency in accordance with monthly sampling schedule.
4. The sample must not have been sorted or graded, only weighed.
5. Each sample is comprised of 50 fish if landing weight is greater than 1000 kg, and at least 20 fish if between 200 and 1000 kg.

Sampling procedure

1. Details are obtained from processor to complete the *Landing record*: i.e., vessel, landing weight (all fish), landed weight of GUR, landing date, statistical area fish caught.
2. Sample is assigned a unique landing number.
3. Fish are randomly selected from the fish bins (method described below).
4. Approximately 10 bins of fish are chosen from which 50 individuals are selected by removing the five fish with their heads closest to the right hand corner of the each bin.
5. Length (FL), sex, gonad stage (5 stage method, see description below) are recorded, and both otoliths are removed and placed in plastic eppendorf vials, then inside otolith envelopes.
6. The full <u>landing number</u>, (e.g. 2010 1101), species, fish number, date, length, sex and sampler initials are recorded on the otolith envelope record.
7. Data are recorded on a waterproof O*tolith Inventory* form
8. A *Landing Record* summary is completed at the end of the sampling.

Gonad staging

Gonad staging used the standard NIWA method with the following five stages for males and females: 1, immature or resting; 2, maturing (oocytes visible in females, thickening gonad but no milt expressible in males); 3, mature (hyaline oocytes in females, milt expressible in males); 4, running ripe (eggs and milt free flowing); 5, spent (gonads flaccid and often bloodshot). These data were summarised and used to generate sex-specific length at maturity ogives.

3.2 Otolith preparation and reading

In February 2010, NIWA held an ageing workshop on red gurnard, attended by NIWA staff that prepared and aged the otoliths from this catch sampling programme. Based on the results of this meeting, the following methods were used.

1. Otoliths were prepared following NIWA's ageing protocols for red gurnard (Sutton 2011) using the bake and embed method for whole otoliths. Otoliths were baked, embedded in a resin block, then sectioned through the primordium using a high speed Gemmasta GS6D® revolving saw. The resulting surface was polished and viewed with a dissecting microscope.
2. Otoliths were examined using reflected light under a stereo-microscope at a magnification of 100×. With transmitted light, the wide opaque zone appears light and the narrow hyaline zone appears dark.

3. Two elected core red gurnard “expert” readers (Colin Sutton and Matt Smith) counted annuli for all otoliths without reference to fish length.
4. The forced margin method was used to assign age for samples taken in months throughout the year (see below).
5. A subsequent rereading of otoliths with discrepant age estimates was carried out by the two readers and a third adjudicating reader (Cameron Walsh) jointly with conferring to determine a final agreed age.

The forced margin method is described in the NIWA red gurnard ageing protocol document (Sutton 2011), and also defined in the glossary of the MFish guidelines for New Zealand fish ageing protocols (Ministry of Fisheries 2011) as follows: **Forced Margin /Fixed Margin** – Otolith margin description (Line, Narrow, Medium, Wide) is determined according to the margin type anticipated for the season/month in which the fish was sampled. The otolith is then interpreted and age determined based on the forced margin. The forced margin method is usually used in situations where fish are sampled throughout the year and otolith readers have difficulty correctly interpreting otolith margins.

In this report, age conforms to the “fishing year age-class” of red gurnard which is defined in MFish guidelines for New Zealand fish ageing protocols as the age of an age group at the beginning of the fishing year (1 October). It does not change if the fish have a birthday during the fishing season.

In the case of red gurnard the wide margin was used for otoliths collected in October–November and were assigned W (wide). The resulting age of a fish recorded as 6W, for example, is 7 years. Otoliths collected from December-January were interpreted as L (Line), or N (Narrow) if collected between February and September. Hence 7L and 7N were assigned age of 7 years. The nominal birthday of red gurnard is taken as 1 January.

Age interpretation and reader consistency were analysed following Campana et al. (1995) and Campana (2001).

3.3 Catch at age estimation

Estimated scaled numbers-at-age were calculated using NIWA Catch-at-length and age software in R (NIWA 2011, R Development Core Team 2011) using the direct ageing procedure (i.e., an age-length key is not used). Age data were scaled in the same way as length data, i.e., by landed weights of red gurnard from the sampled vessels, and by commercial catch from the sampling strata. Scaled age-frequency distributions were estimated by sex, and overall for two post-hoc strata (summer vs winter samples, and samples from north vs south of Mahia Peninsula). The MWCVs were estimated by sex and overall using a bootstrapping routine (300 bootstraps).

3.4 Growth parameter estimates

A von Bertalanffy growth model was fitted to the length-age data, by sex using the model:

$$L_t = L_\infty \, (1 - \exp^{-K[t - t0]})$$

Where L_t was the length (cm) at age t, L_∞ the asymptotic mean maximum length, K was a constant (growth rate coefficient), and t_0 was the hypothetical age (years) that a fish has zero length. Age was one year less for fish sampled between October and December.

The proportion mature P_m was modelled as a function of length (L) or age (A) using a binomial distribution with logit link:

P_m = alpha + beta * L *or* A
$L_{50\%}$ or $A_{50\%}$ = - (alpha / beta)

Macroscopic gonad stages 1 and 2 were considered immature for this analysis.

3.5 Mortality estimates

Total mortality (Z) was estimated from catch-curve analysis using the Chapman-Robson estimator (CR, Chapman & Robson 1960, Robson & Chapman 1961). The CR method has been shown to be less biased than the simple regression catch curve analysis (Dunn et al. 1999). Catch curve analysis assumes that the catch of fully recruited age classes declines exponentially with age and that the slope is equivalent to equilibrium total mortality experienced by the population, the sum of natural and fishing mortality, $Z = (M + F)$. Implicit in this are the assumptions that recruitment and mortality are constant, that all fully recruited fish are equally vulnerable to capture, and that there are no age estimation errors.

We used the method of Dunn et al. (1999) to estimate the variance (95% confidence intervals) for age at full recruitment of 2 and 3 years for both sexes combined. Estimates of total mortality, Z, were calculated for age at full recruitment (a_{rec}) using the maximum-likelihood estimator

$$\hat{Z} = \log_e \left(\frac{1 + \bar{a} - a_{\text{rec}}}{\bar{a} - a_{\text{rec}}} \right)$$

where $\bar{a} = \left(\sum_a^{\text{rec}} a f_a \right) \Big/ \left(\sum_a^{\text{rec}} f_a \right)$ is the mean age of recruited fish in the combined sex age frequency, and $\sum_a^{\text{rec}}$ denotes summation across all recruited ages.

A point estimate of natural mortality (M) was calculated following Hoenig (1983) as –ln (0.01)/A_{max}, where A_{max} is the maximum observed age, representing the mortality rate that would leave 1% of the original population abundance after A_{max} years.

3.6 Historical length and age distributions

Data from previous catch sampling programmes and bottom trawl surveys were summarised from relevant technical reports for comparison with data generated in the present study.

3.7 Catch Sampling Design Optimisation

Data collected during this project are useful in estimating the sample size needed to achieve a desired level of precision in future catch sampling programmes. The optimal sample size, both in numbers of landings sampled, and in the numbers of otoliths read per sampled landing, depends on the number of age classes present and the variation in age composition of catch among the sampled landings within each stratum. For GUR 2, no strata were defined, but seasonal representation is desirable, so optimal sample size was determined for two *post hoc* strata (autumn-winter, and spring-summer). The simulations were conducted using a bootstrap routine used to optimise catch sampling of snapper (Davies 2003). The optimal sample size is the number of samples required to achieve a particular MWCV. Typically, catch sampling programmes in New Zealand target a MWCV of less than 0.30. However, the target MWCV should be less than 0.30 as the realized MWCV will depend on the actual catch sampled, which may vary substantially among years. Also, the lower the MWCV, the more power to observe structure within the GUR 2 catch, such as temporal, spatial, or operations (e.g., gear type) differences in catch composition. The simulation study carried out here provides estimates of

MWCVs for various combinations of numbers of sampled landings and the number of otoliths sampled per landing, leaving the decision of final sampling design to future sampling design approval.

4. RESULTS

4.1 Catch sampling summary

Catch sampling targeted 40 landings spread throughout the fishing year (October 2009 through to September 2010). Forty samples of 50 fish each were collected, although the number of landings sampled each month varied modestly from the target due to fish availability (Table 2).

Table 2: Numbers of GUR 2 landings targeted by month and the number obtained, 2009–2010. Each sampled landing consisted of 50 fish.

Month	Samples targeted	Samples obtained
October	6	5
November	5	5
December	6	7
January	3	3
February	3	3
March	2	1
April	2	2
May	2	2
June	2	2
July	2	3
August	2	3
September	5	4
Total	40	40

4.2 Minimum landing size

The cumulative proportion of landings by weight and number indicated that by restricting samples to landings greater than 200 kg, almost 90% of the landed weight would be available for sampling while reducing the number of potential trips by more than 60% (Figure 7a). The working group recommended a landing weight threshold of 200 kg for the 2010 sampling year.. In 2010, 57% of landings were less than 200kg, but these landings comprised only 7% of the total GUR2 reported catch (Figure 7b). The remaining 43% of landings (i.e. those greater than 200kg) therefore contained 93% of the catch.

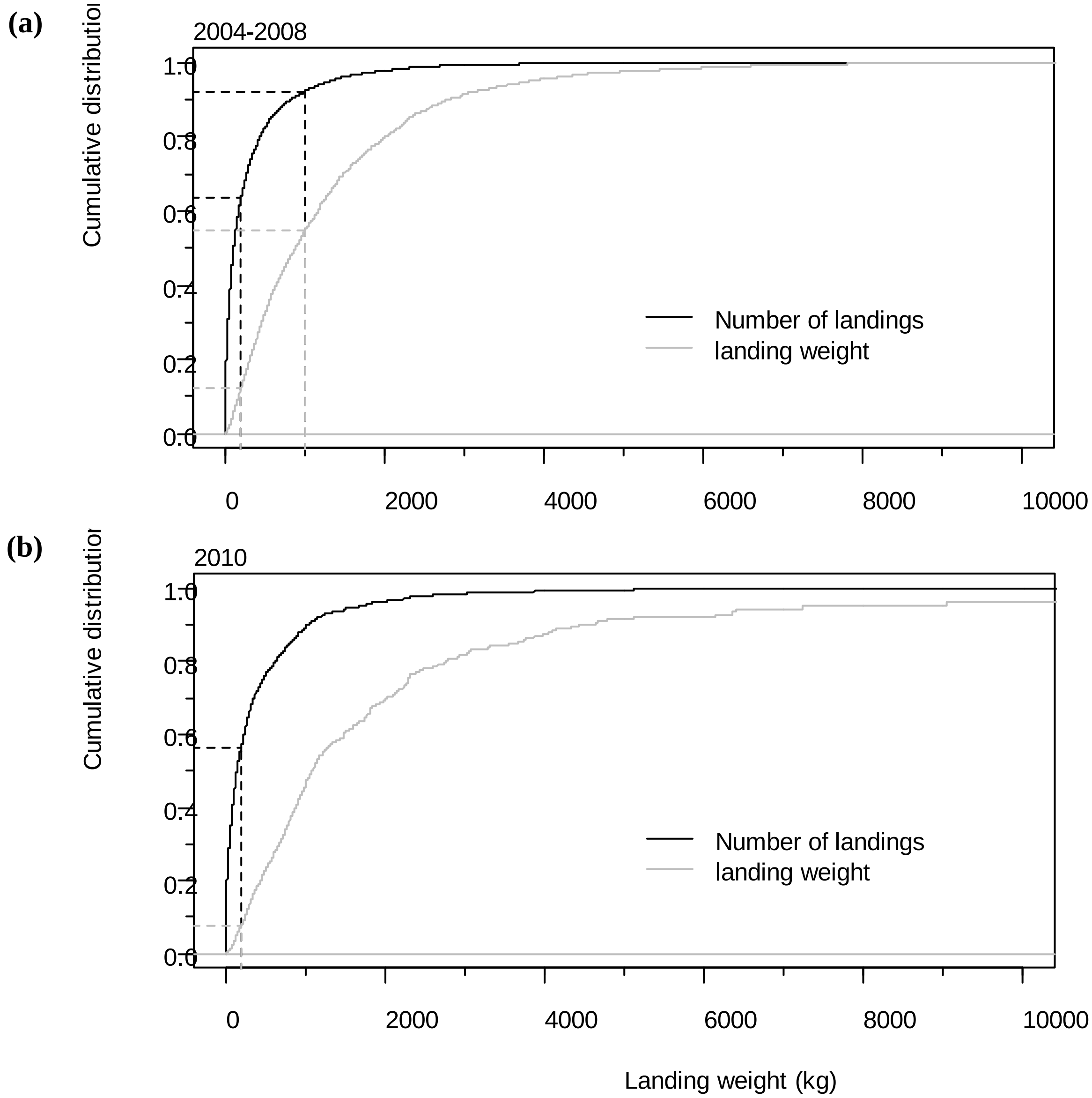

Figure 7: Cumulative proportions of GUR 2 landings by weight and number (a) from 2004–2008 used to plan catch sampling in 2009–2010 and (b) the actual distributions from 2010. Horizontal and vertical lines indicate the proportion of landings and cumulative weights below the 1000 kg and 200 kg sampling thresholds.

4.2.1 Representativeness

The depth distribution of sampled catch was very similar to the depth distribution of all GUR 2 target tows (Figure 8). The depth distributions of trips landing GUR 2 were somewhat bimodal in statistical areas 011, 012, 014, and 015, and which is likely to be due to a mix of TAR target and other species target tows, which had somewhat deeper median depths than GUR target tows (Figure 8). GUR target tows had a similar depth range to SNA target, and slightly deeper than FLA target tows (Figure 9).

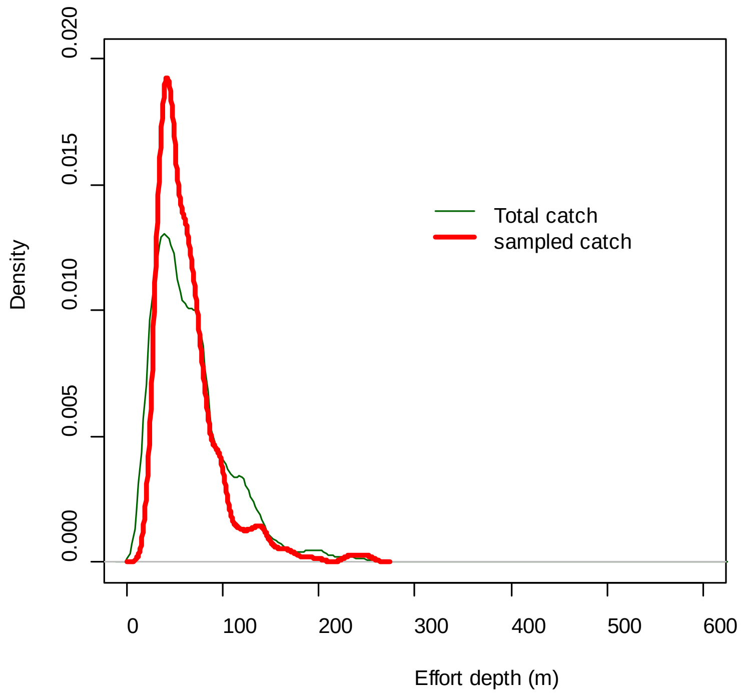

Figure 8: Depth distribution of GUR 2 target fishing in 2010 for all tows and for tows from trips where catch was sampled for length and age distribution.

(a)

(b)

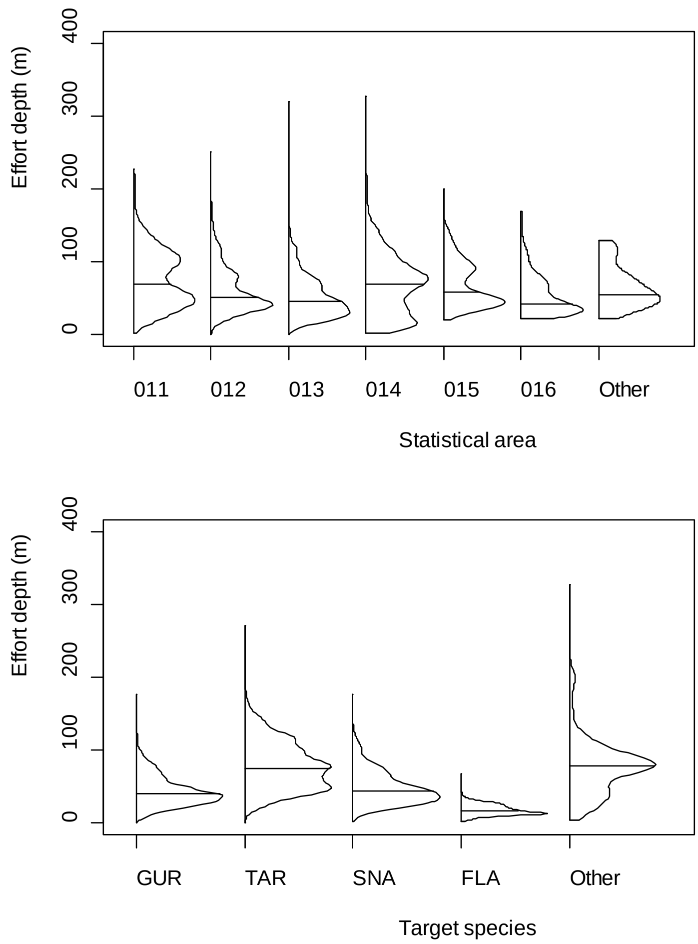

Figure 9: Depth distribution of tows from trips landing GUR 2 by (a) statistical area and (b) by target species. Horizontal line indicates median of the distribution.

Ideally, the relative proportion of sampled catch each month would roughly equal the relative proportion of total landings each month. This would also be true for statistical area and target species. However, as the total landed catch is never known in advance, the programme is designed to oversample fish and then select fish for ageing in the correct proportion. The sampled catch was over-represented in the first two months of the programme, well sampled during summer months, and under sampled in the winter months (Figure 10a). Samples from each statistical area were well represented except for statistical area 015, which was oversampled (Figure 10b). Samples for each target species were also well represented (Figure 10c). Otoliths were selected in proportion to the relative landed weight in each month, mirroring the landed weight proportions while ensuring adequate numbers of otoliths were available for each level (Table 3).

Table 3: Distribution of landed weight, otoliths collected and otoliths selected for ageing in relation to month, target species, and statistical area. Note that otoliths cannot be allocated to statistical area because a single trip may fish in multiple statistical areas (sampling trips from a single statistical area was not a constraint on sampling).

Month	Landed weight (kg)	Proportion of landed weight	Otolith pairs collected	Otolith pairs selected	Proportion of otoliths selected
Oct	13 721	0.23	252	188	0.17
Nov	13 817	0.23	301	194	0.17
Dec	8 132	0.14	300	194	0.17
Jan	2 782	0.05	150	74	0.07
Feb	5 902	0.1	150	127	0.11
Mar	714	0.01	100	22	0.02
Apr	2 671	0.04	100	60	0.05
May	4 853	0.08	100	60	0.05
Jun	333	0.01	97	20	0.02
Jul	1 305	0.02	152	39	0.03
Aug	1 722	0.03	149	54	0.05
Sep	3 753	0.06	200	92	0.08
Target					
FLA	66	0	50	10	0.01
GUR	454	0.01	50	12	0.01
TAR	45 980	0.77	1402	828	0.74
Statistical area					
011	522	0.01			
012	4 993	0.08			
013	26 031	0.44			
014	8 406	0.14			
015	19 150	0.32			

(a)

(b)

(c)

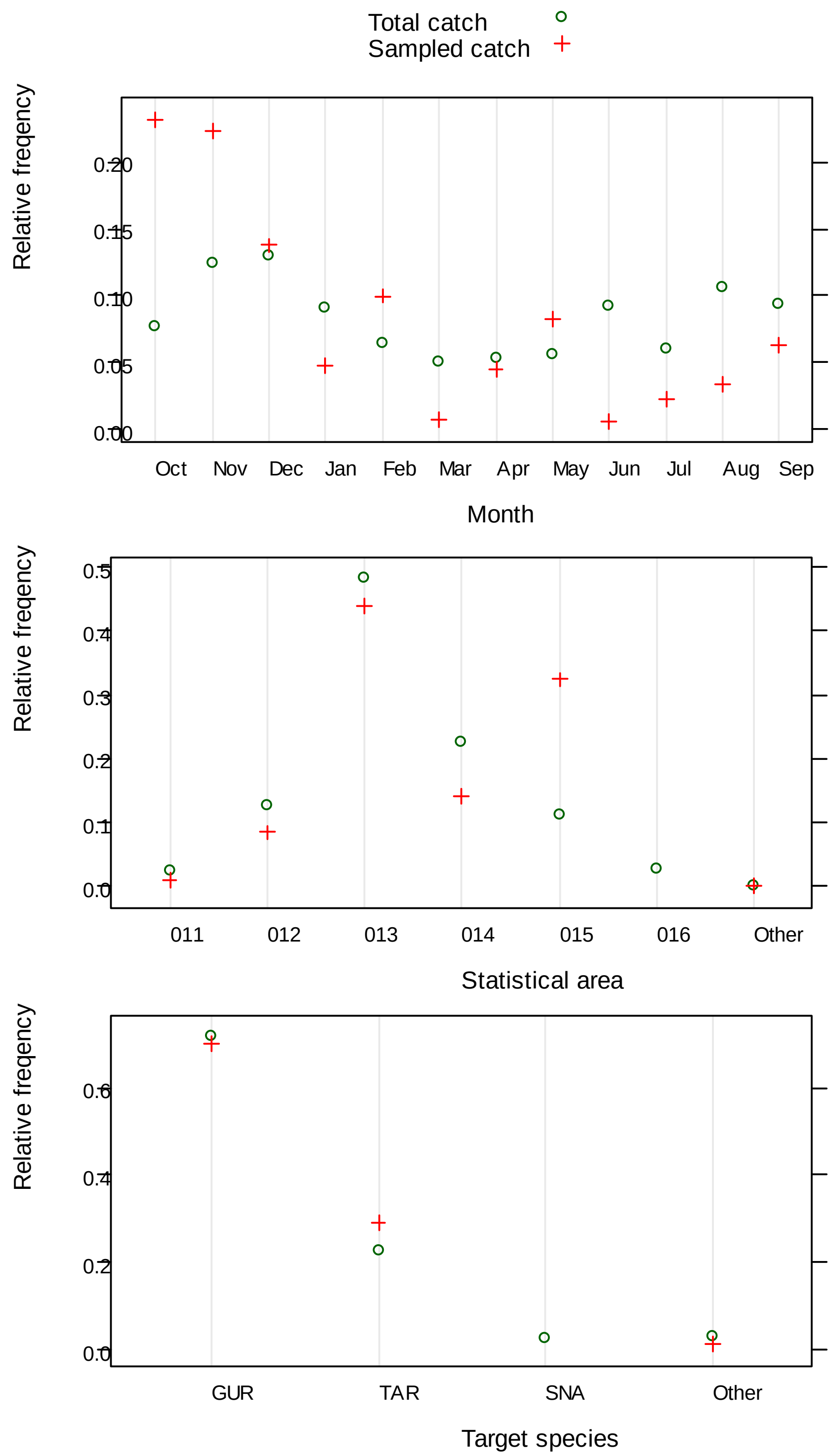

Figure 10: Proportion of total landed GUR2 catch (circles) and the portion of total catch sampled (crosses) in each (a) month, (b) statistical area, and (c) by target species during the 2009-2010 fishing year.

The relative proportion of landed catch by each licensed fish receiver (LFR) varies substantially by year (Figure 11). The 2010 catch sampling programme was designed based on the 2004–2008 catch, and six LFRs were selected to provide catch for sampling. Samples were acquired at LFRs A, D, E, F, and H and two more from the “other” category (Figure 11).

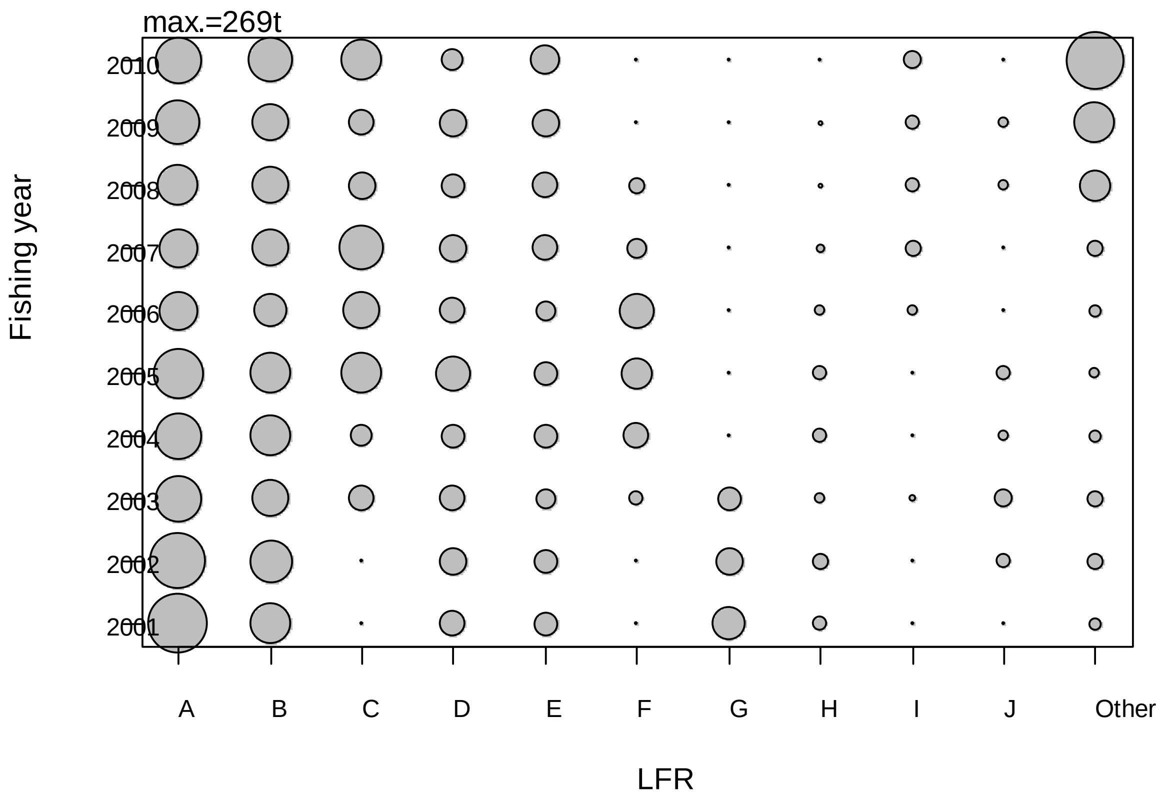

Figure 11: Proportion of landings by the top 10 licensed fish receivers from 2001–2010. Landings were sampled in 2010 from LFRs A, D, E, F, H and Other (2).

4.3 Length composition of the catch

Although no formal strata were designated, a *post hoc* stratification of samples from north and south of the Mahia Peninsula was made to determine if different length compositions were observed as suggested in other species such as snapper. However, to do this catch from each trip must be allocated to either side of a boundary within a statistical area. Within statistical area 013, catch for the trip was allocated to either north or south of the boundary (or dropped). Fortunately, TCER data provided locations of individual tows capturing gurnard, and only four trips had tows spanning the boundary. The gurnard catch for each of the tows of those trips was plotted (Figure 12), and provided justification for allocating the catch to a particular stratum. Based on this plot, only one of the four trips (red symbols) was allocated to the southern stratum.

Scaled length distributions for males and females were different, with males being smaller than females and having a narrower length distribution (Figure 13). Mean size was 33 cm for males, and 36 cm for females. Maximum length for females was more than 50 cm, while males did not exceed 45 cm. There was no substantive difference in the length distributions north and south of Mahia Peninsula, although MWCVs were high.

When length data were stratified by season, spring-summer samples showed the presence of smaller fish (approximately 20–25 cm) of both sexes, which were absent in winter-autumn (Figure 14). This is likely to be the effect of young, fast growing fish attaining a size that becomes progressively selected by the fishery throughout the year.

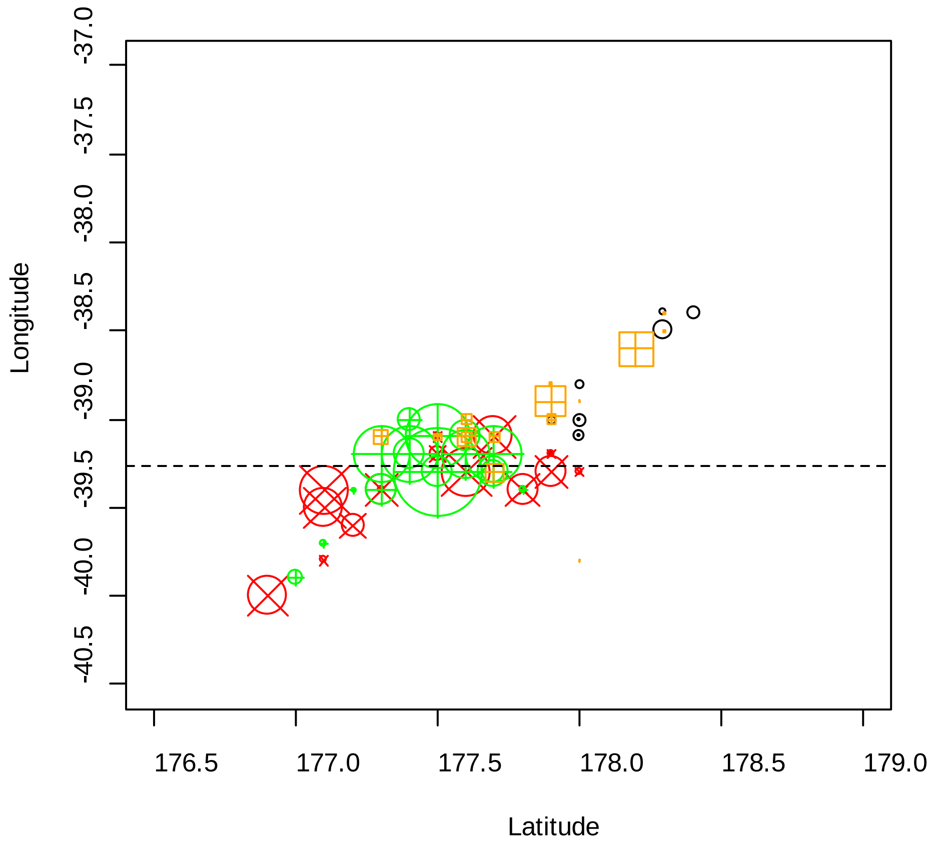

Figure 12: Locations and relative amount of catch per tow for four trips that straddle the 39.264 degree line of latitude used as a *post hoc* stratification of landings. Different symbols represent the location and magnitude of estimated catch for each different trip.

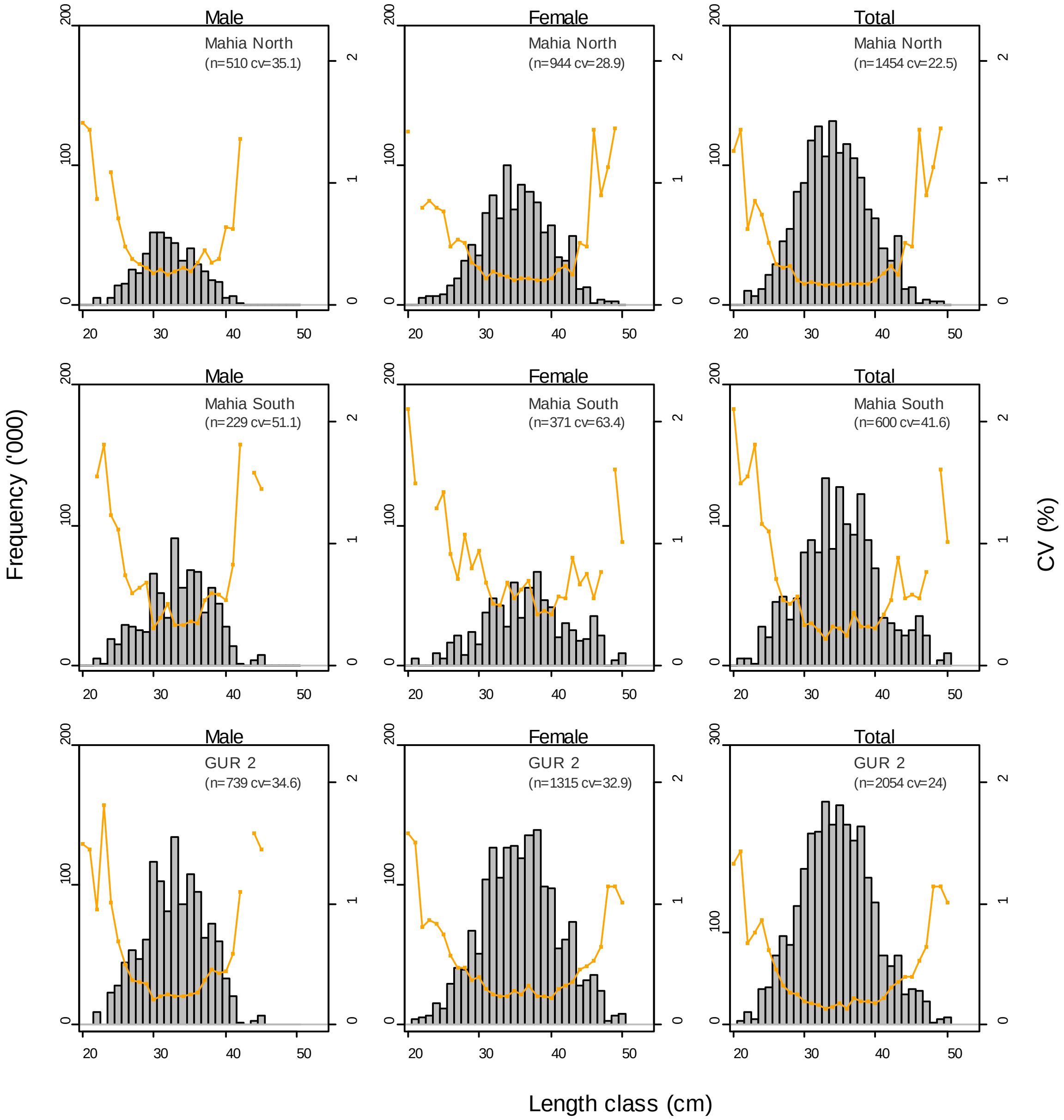

Figure 13: Scaled length frequency distributions for GUR 2 landings in the 2010 fishing year, segregated by sex, and stratified for fish north and south of Mahia Peninsula. Lines indicate the c.v. for each length.

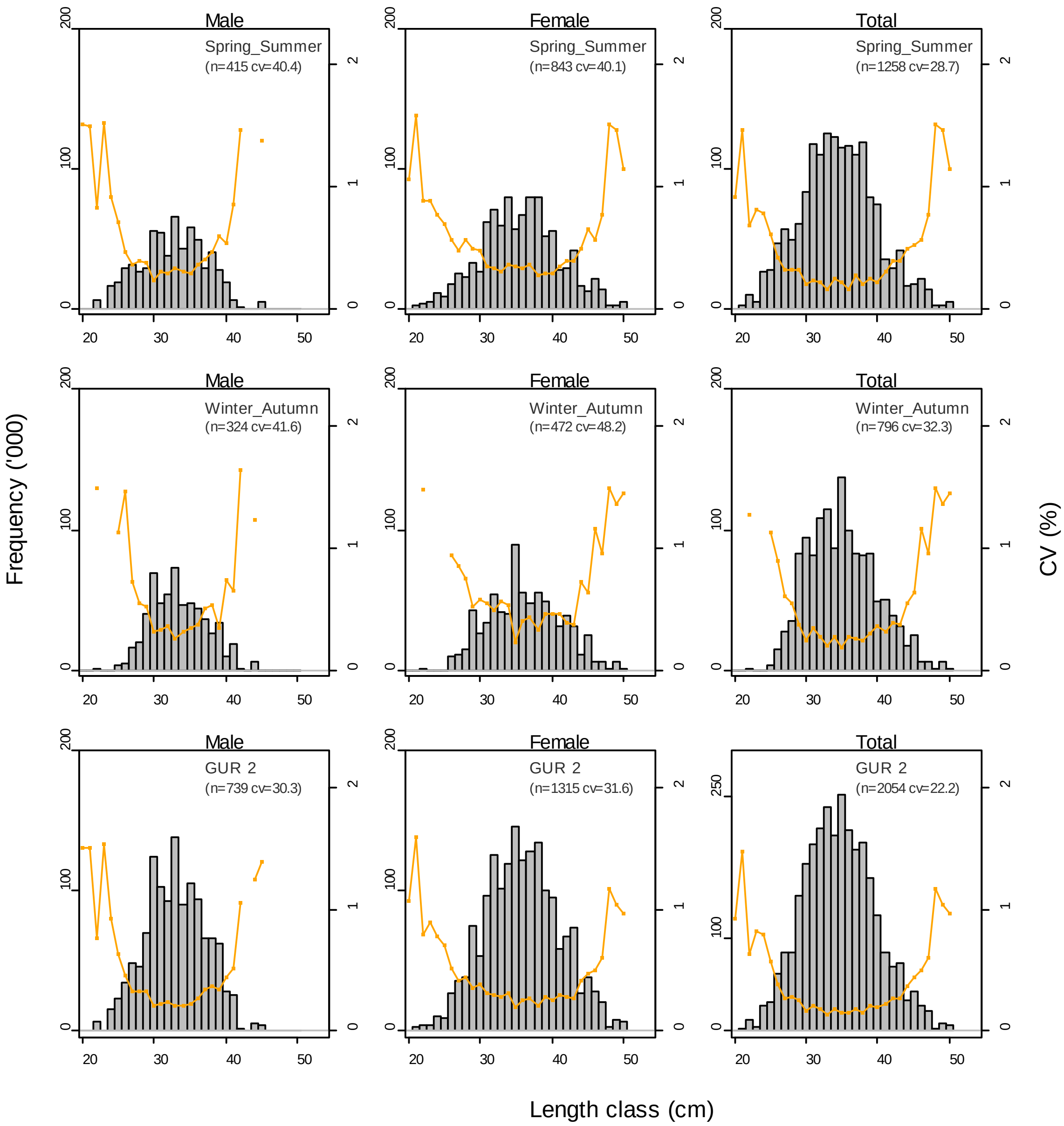

Figure 14: Scaled length frequency distributions for GUR 2 landings in the 2010 fishing year, segregated by sex, and stratified by spring-summer or autumn-winter periods. Lines indicate the c.v. for each length.

4.3.1 Age determination

Ages were estimated for a total of 1078 otoliths, the number being limited by available budget and set by the Inshore Working Group (7 December 2010). Age readings were consistent between readers, with an average percent error (APE) of 6.04 and a MWCV of 8.55% (Figure 15). Only 288 of 1078 readings (34%) disagreed at all, and only 4% disagreed by more than 1 year (Figure 15 a, b). The second reader tended to underestimate age compared to the first reader, especially for ages between 5 and 10 years (Figure 15 b, c). This discrepancy was resolved through a conferring process and a final agreed age was determined. Protocols for annulus readings were updated to avoid future discrepancies of this type. At this time, no reference set exists for red gurnard, so no assessment of reader drift was made.

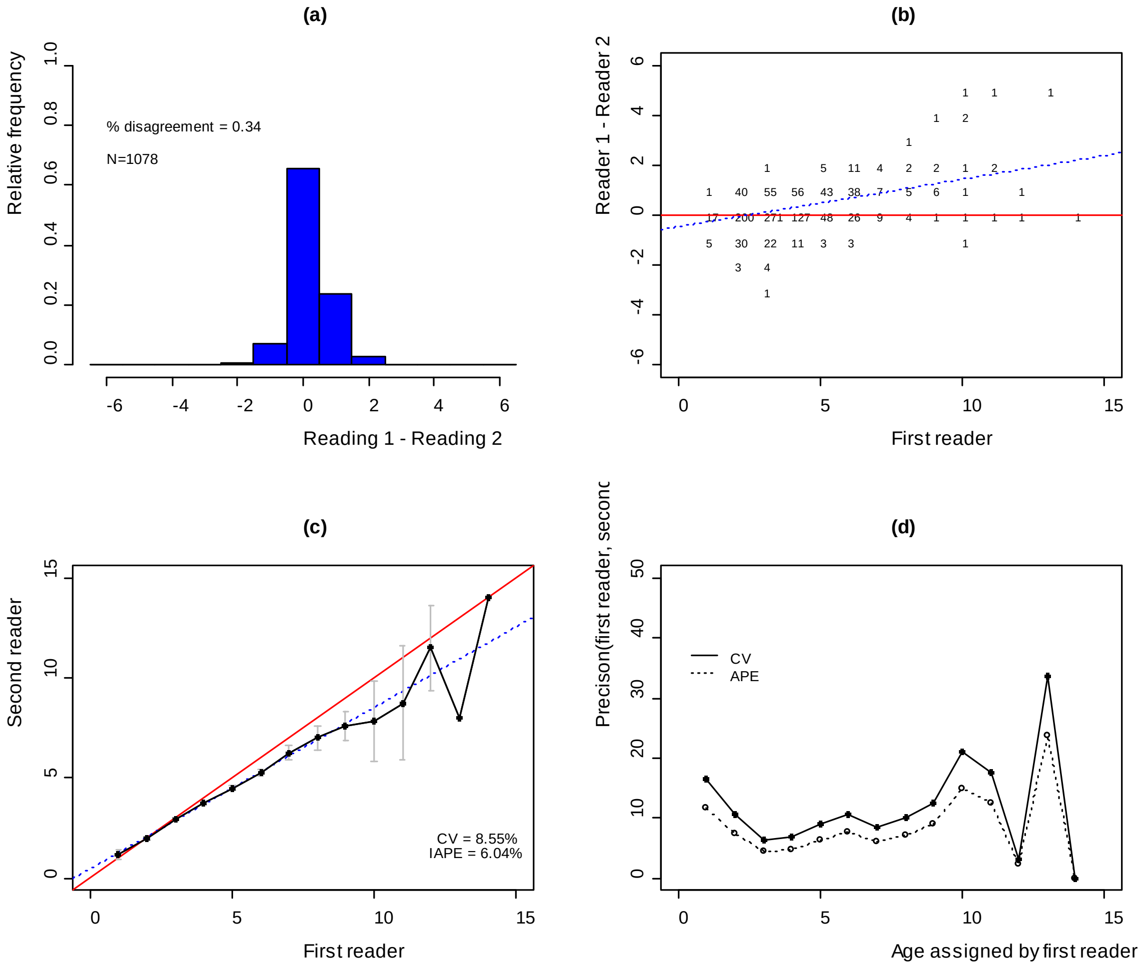

Figure 15: Age reader comparison plots. (a) histogram of age differences between two readers. (b) difference between reader 1 and reader 2 as a function of the age assigned by reader 1. The number of fish in each bin is plotted as the plot symbol. (c) Age bias plot, showing the correspondence of ages between reader 1 and reader 2 for all ages. Error bars indicate the c.v. of the ages for each age by reader 1. (d) Plot of the c.v. and the average percent error (APE) for each age as assigned by the first reader. Solid lines show perfect agreement, dashed lines show a linear regression line for the data points.

4.4 Age composition of the catch

The vast majority of the GUR 2 catch was less than six years old and dominated by two and three year old fish (Figure 16). Almost no fish were greater than 10 years of age and the maximum age observed was 14. Similar age distributions were sampled in summer and winter months, and between males and females, though MWCVs were high for these subsample comparisons. The overall MWCV for the composite age distribution was 0.15.

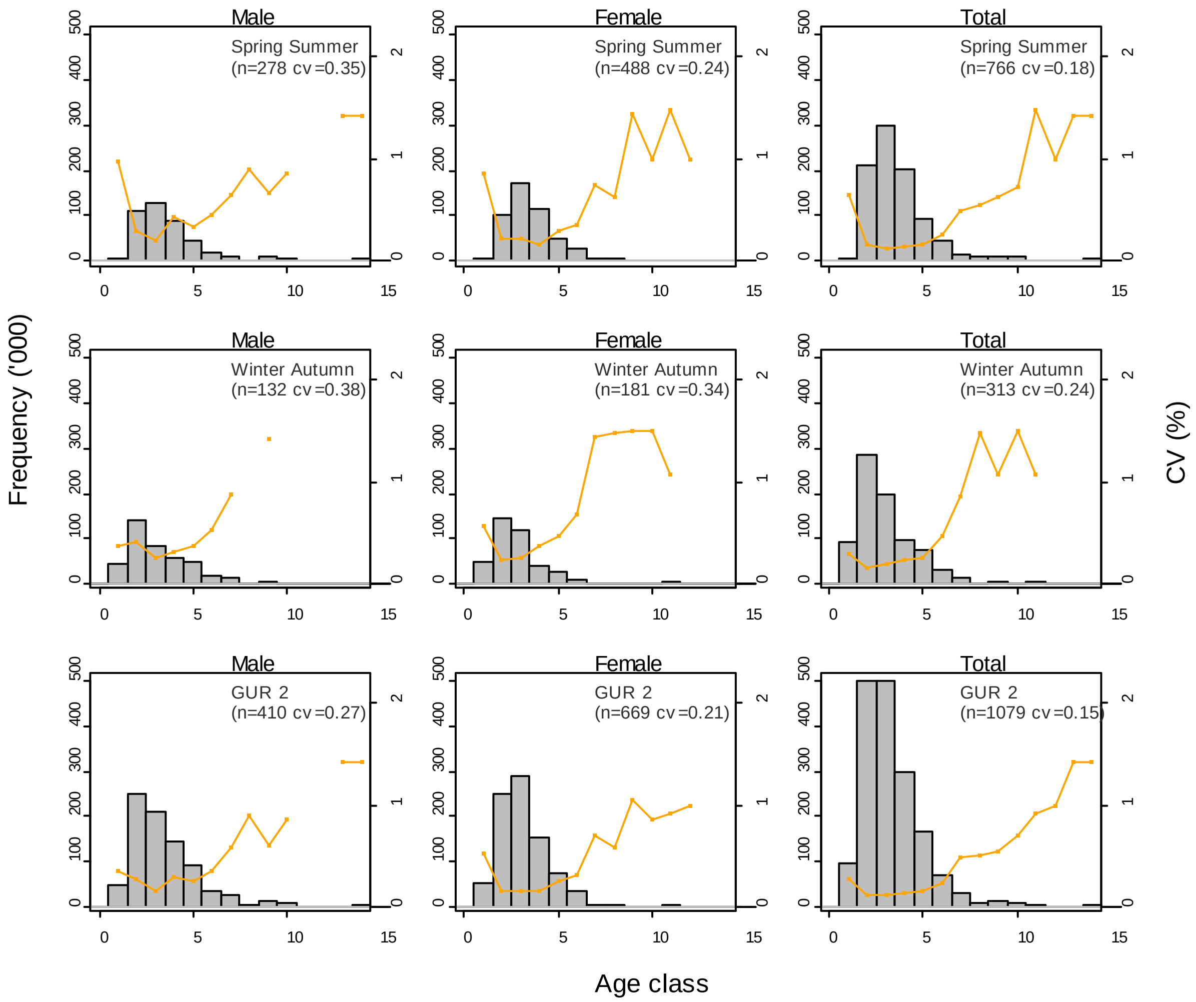

Figure 16: Scaled age frequency distributions for GUR 2 landings in the 2010 fishing year, segregated by sex, and stratified by spring-summer or autumn-winter periods. Lines indicate the c.v. for each age.

4.5 Mortality estimates

Based on a maximum age of 15 years, the point estimate of *M* following Hoenig's method (Hoenig 1983) is 0.307.

Chapman-Robson estimates of total mortality (*Z*) depend on the age of full recruitment to the fishery (Chapman & Robson 1960). This age is usually estimated from the scaled age composition as the age class with the peak abundance, or one year after that age. We estimated the total mortality for full recruitment at age 2 and 3 as 0.518 (SE = 0.0159, c.v.=3.1%) and 0.632 (0.0196, 3.1), respectively. Subtracting the estimate of natural mortality leaves an estimate of *F* equal to 0.189 or 0.303. The estimate of *Z* between 0.5 and 0.6 has been consistent among all the studies producing a *Z* estimate, even as far back as Elder (1976) with *Z* estimates of 0.60 and 0.65 for females and males.

Although it was not possible to produce reliable estimates of spawner biomass per recruit based targets of F (due to unreliable estimates of growth rate, a truncated population age structure in the catch, and uncertain size at maturity), it is worth mentioning that estimates of F from this study were approximately equal to the estimate of natural mortality. Natural mortality may be used as a target for fishing mortality (i.e. F=M), and is included as a proxy for F_{msy} in the MPI Harvest Strategy Standard. Given that catches have been relatively constant over the last few decades, these results suggest that GUR 2 was not over-exploited in 2010.

4.5.1 Life history parameter estimates

Life history parameters of red gurnard (growth, natural mortality, length-weight, and maturity) have been reported from a number of studies, and from a number of regions (GUR 1W, GUR 1E, GUR 2, Sutton 1997, Ministry of Fisheries 2010). However, each study has concluded that spatial effects from sampling, and observed differences in growth functions makes assuming values from other studies dubious. In addition, because each study is typically spatially and temporally restricted, and does not report all of the parameters, model fits are often poor.

The same is true of the present study, where although length at age data were collected and fit, the lack of small and juvenile fish and of large and old fish results in a poor fit to the von Bertalanffy growth function and yields different values from other studies. Indeed, the maturity data are inconsistent with the von Bertalanffy growth functions, with the $L_{95\%}$ for maturity being greater than the L_{∞} value for the growth function (Figure 17, Table 4).

Having poor representation of the full age distribution for fitting life history parameter functions was due to ageing otoliths under a random age frequency strategy. More than 2000 fish were randomly sampled, but only 1 079 at random were aged, and therefore specimens from both tails of the age distribution are not well represented in the sample aged, even if they were collected. Studies with an objective to estimate life history parameters may need to collect stratified samples in addition to those collected for age composition.

Poor fits and dated data (e.g., Elder 1976 for length-weight parameters) mean that the currently available data are not suitable as input parameters for spawner per recruit analyses. If these analyses are desired in the future, detailed sampling of individual weights, maturity status, and stratified sampling to obtain data from very large and very small individuals of each sex should be considered.

Table 4: Life history parameters estimated for red gurnard in GUR 2 from this study; a and b are estimated from $W=aL^b$, where W is weight (g) and L is length (cm).

Parameter	Females	Males
Length-weight		
a	0.0053	0.0053
b	3.19	3.19
von Bertalanffy		
L_{∞}	43.14	36.27
K	0.34	0.52
t_0	-2.37	-1.84
N	667	410
Natural mortality	0.307	0.307
Maturity		
$L_{50\%}$	31.59	36.06
$L_{95\%}$	44.64	41.86

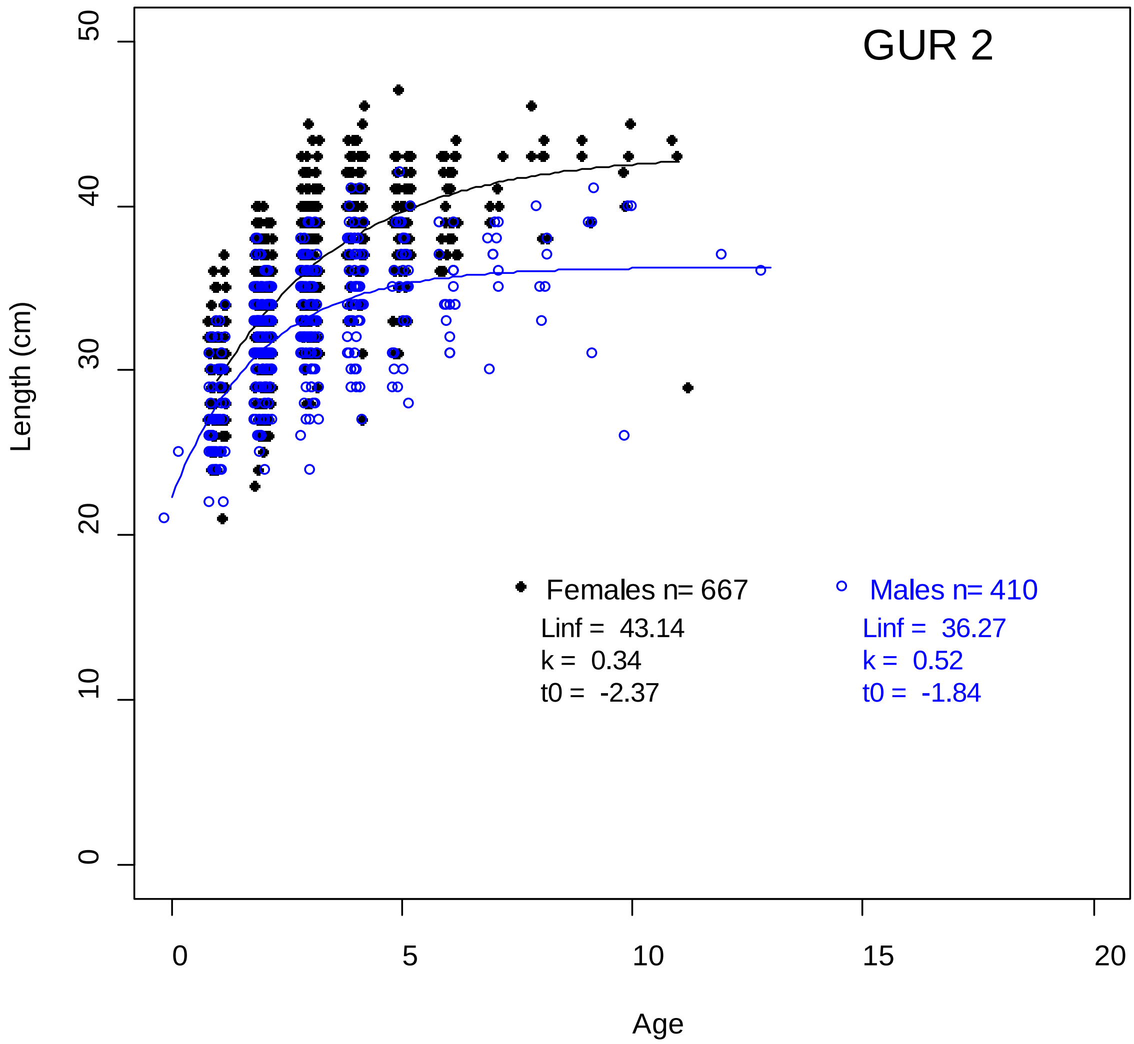

Figure 17: Length at age observations for male and female red gurnard (points) and the von Bertalanffy growth model fits (female:thin black line, male: thick blue line) for fish aged from the 2009–2010 catch sampling programme.

4.5.2 Maturity

Maturity samples showed evidence of spent fish (stage 5) throughout the year, although most spent fish were observed in autumn (March–July), with a notable exception of no mature fish in the June samples (Figure 18). This contrasts with a summertime birthdate derived from samples by Elder (1976). The lack of a synchronised spawning period was also observed in the Hauraki Gulf. Typically, only months in which active preparation for spawning occurs are included in the estimation of length at maturity ogives as resting fish are often difficult to classify compared with immature fish in the non-spawning season. In this case, no appropriate period was identifiable, but including all samples results in no ogive fit. Therefore, samples were restricted to January through to May as the best approximation to the maturation period, which resulted in the best ogive fit for the data (Figure 19). The resulting maturity ogives indicate length at 50% maturity of 31 cm for females and 36 cm for males. However, the ogives are relatively flat, with females maturing between 25 and 40 cm, making the relationship uninformative. In addition, these $L_{50\%}$ values are much higher than the $L_{50\%}$ values estimated by Elder (1976) of 21 cm for males and 25 cm for females.

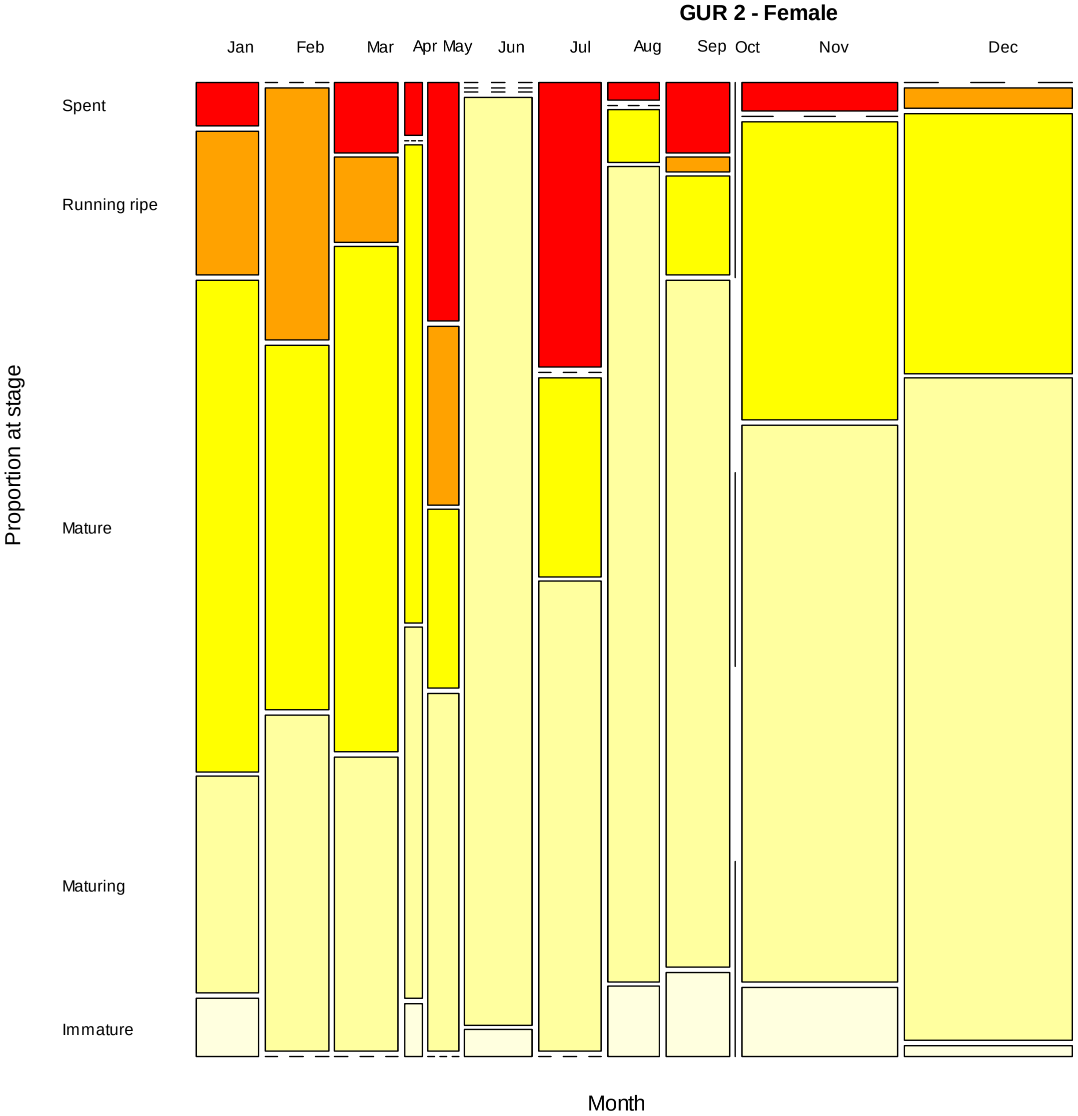

Figure 18: Proportion of female red gurnard in each maturity stage by month sampled. Bar width is proportional to the number of samples in each month.

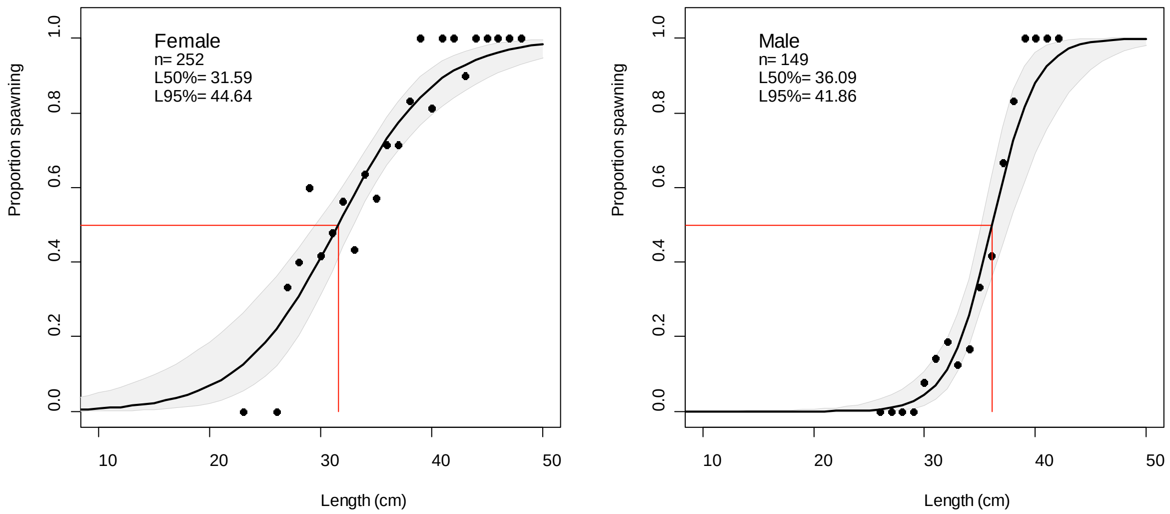

Figure 19: Length at maturity ogives for female and male red gurnard for samples collected from January through to May from GUR 2. Red lines indicate the $L_{50\%}$ for each sex. Gray shaded regions indicate the 95% confidence interval for the ogive.

4.6 Comparison with previous length and age composition studies

Several studies have been conducted to describe the length and age composition of GUR 2 stocks and landed catch (Elder 1976, Stevenson & Hanchet 2000, Horn et al. 2006), and the abundance of GUR 2 stocks from CPUE and survey data (Hanchet et al. 2000). The length composition estimates from these studies are remarkably consistent despite spanning 35 years. Length distributions are typically uni-modal, showing no evidence of size mode progression of different year classes, and are broad, ranging from 20–50 cm for females and 20–45 cm for males, though the samples summarized by Elder were somewhat smaller overall, and may be related to his sampling of shallow coastal and estuarine regions (Figure 20–Figure 22).

The pattern in age composition is also consistent, with the most abundant age class of two, while females show a broader age distribution with the most abundant age class being 3 or greater (Figure 23–Figure 25). The consistent interpretation of these data is that red gurnard have an ontogenetic movement from inshore and shallow waters out to deeper waters as they grow, and that males move to deeper waters before females. Elder (1976) also suggested an annual inshore-offshore migration that was less pronounced.

The other consistent feature in biomass surveys is high variation in abundance, which may also be related to the annual spatial distribution of the population relative to the surveyed area and can generate differences in length or age composition if survey samples are spatially or temporally restricted (Hanchet et al. 2000, Stevenson & Hanchet 2000).

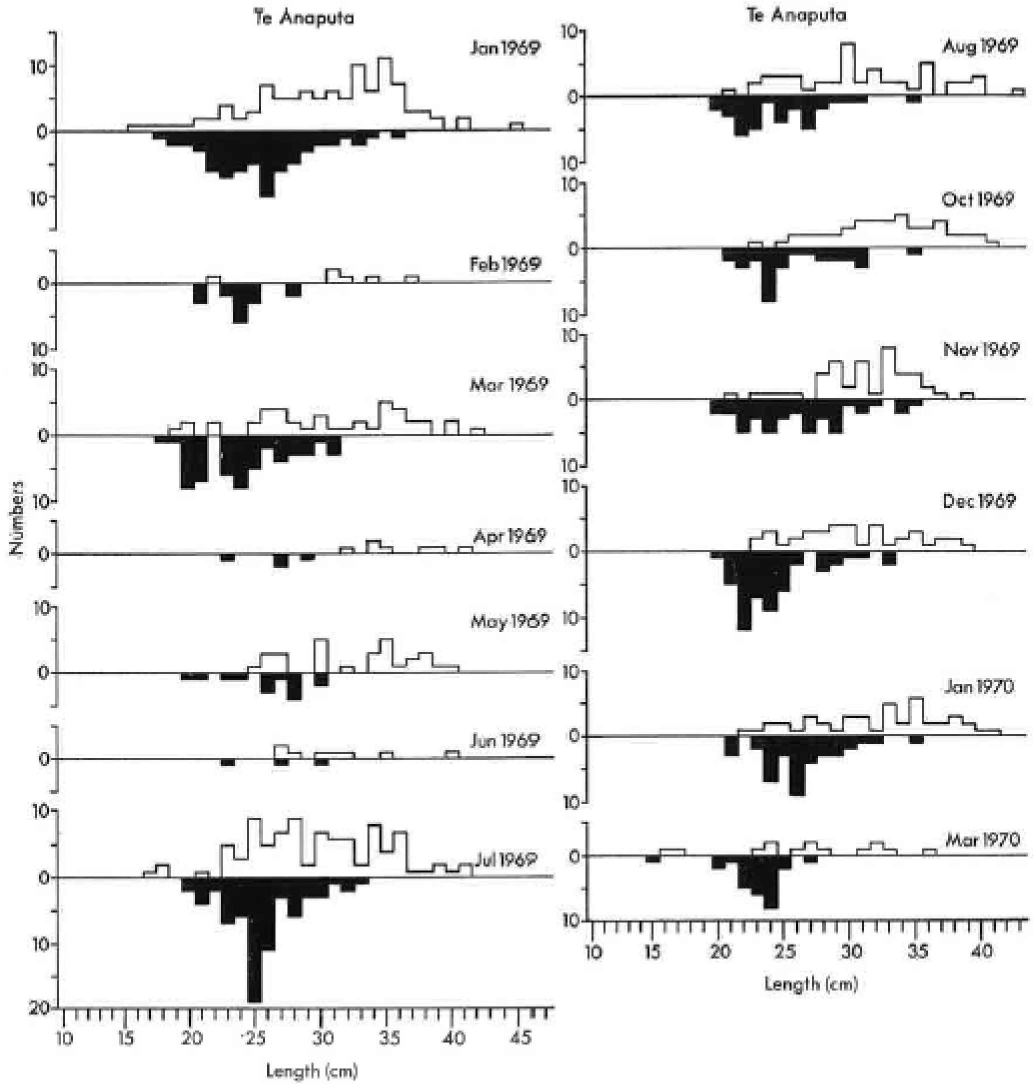

Figure 20: **Length distributions of red gurnard from Te Anaputa, 1969–1970 from Elder (1976). White indicates females and black indicates males.**

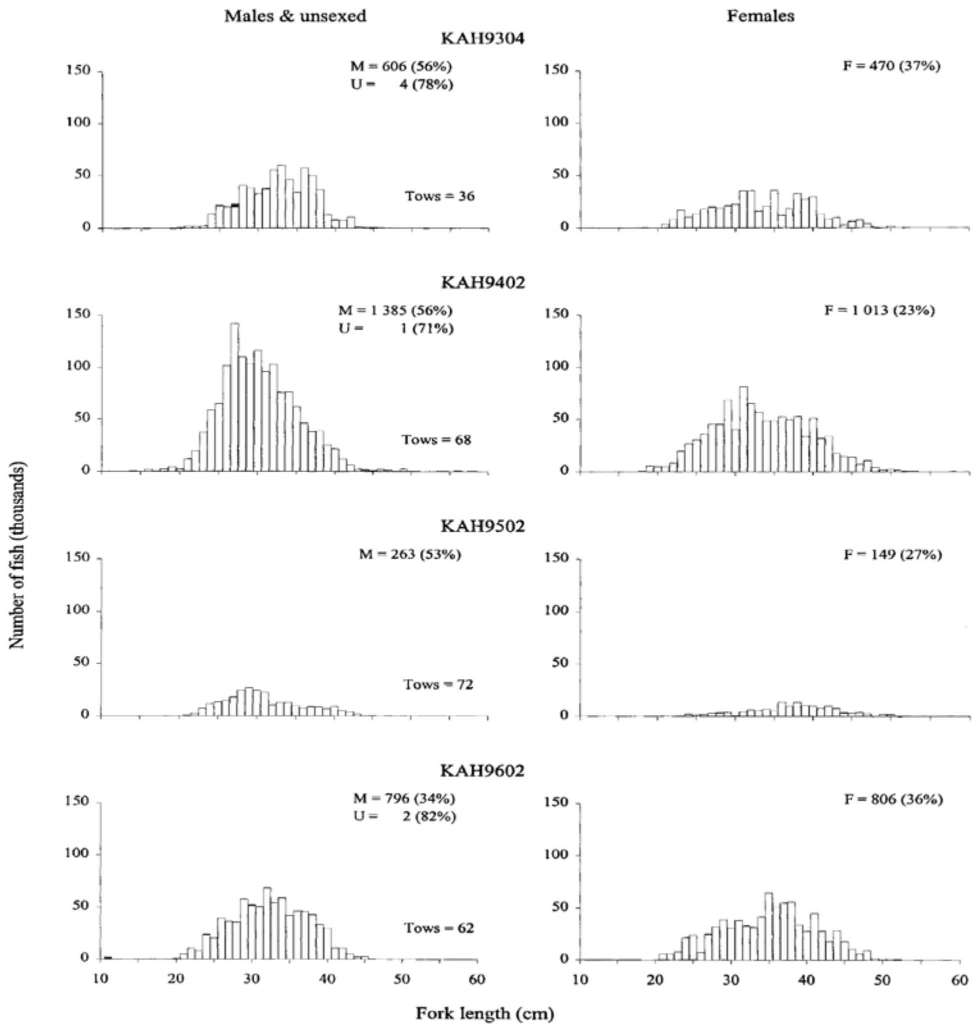

Figure 21: Scaled length distributions for male and unsexed, and female red gurnard from four east coast North Island surveys 1992–1996 from Stevenson & Hanchet (2000).

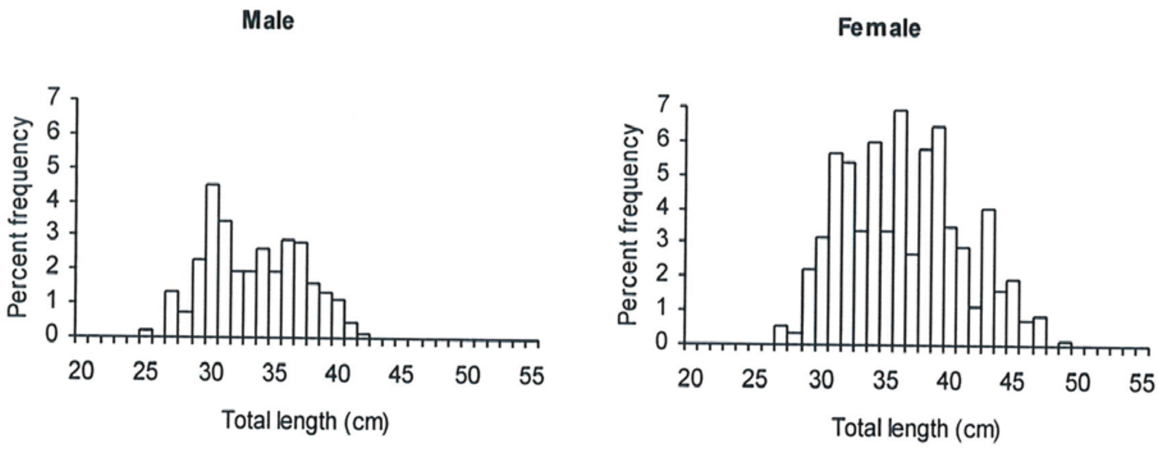

Figure 22: Scaled length distributions of male and female red gurnard from 2004–05 bottom trawl fisheries in GUR 2 from Horn et al. (2006).

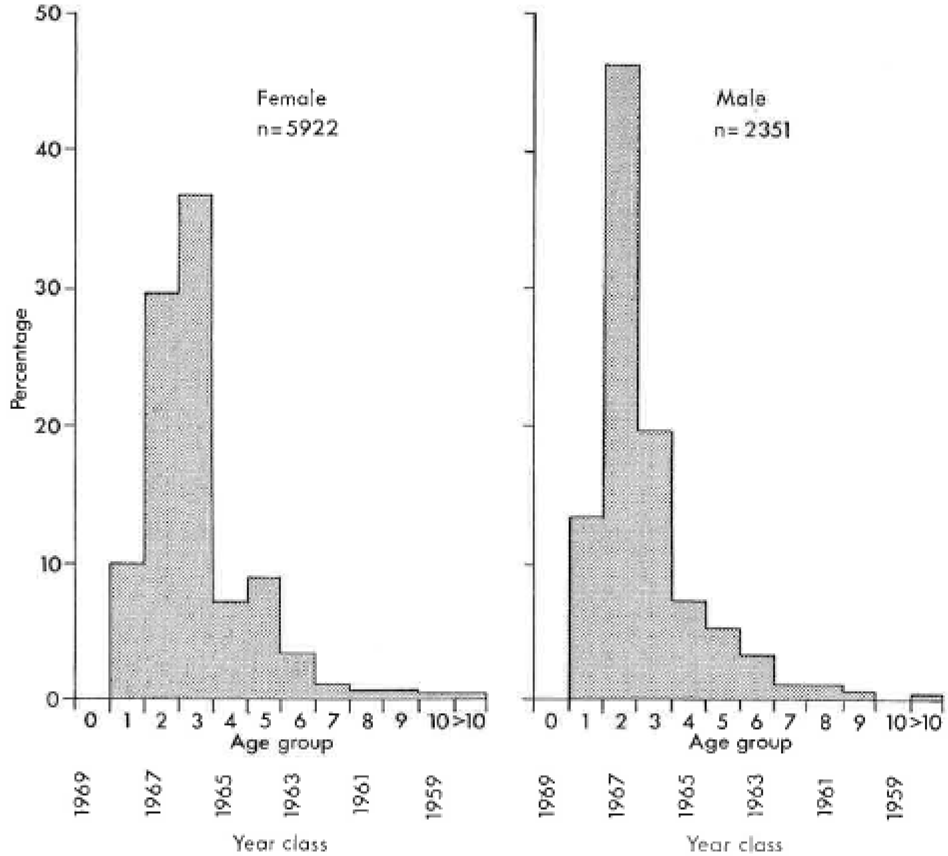

Figure 23: Unweighted age composition for all samples of male and female red gurnard aged from the Hauraki Gulf from Elder (1976). Years indicate the year the age group was hatched.

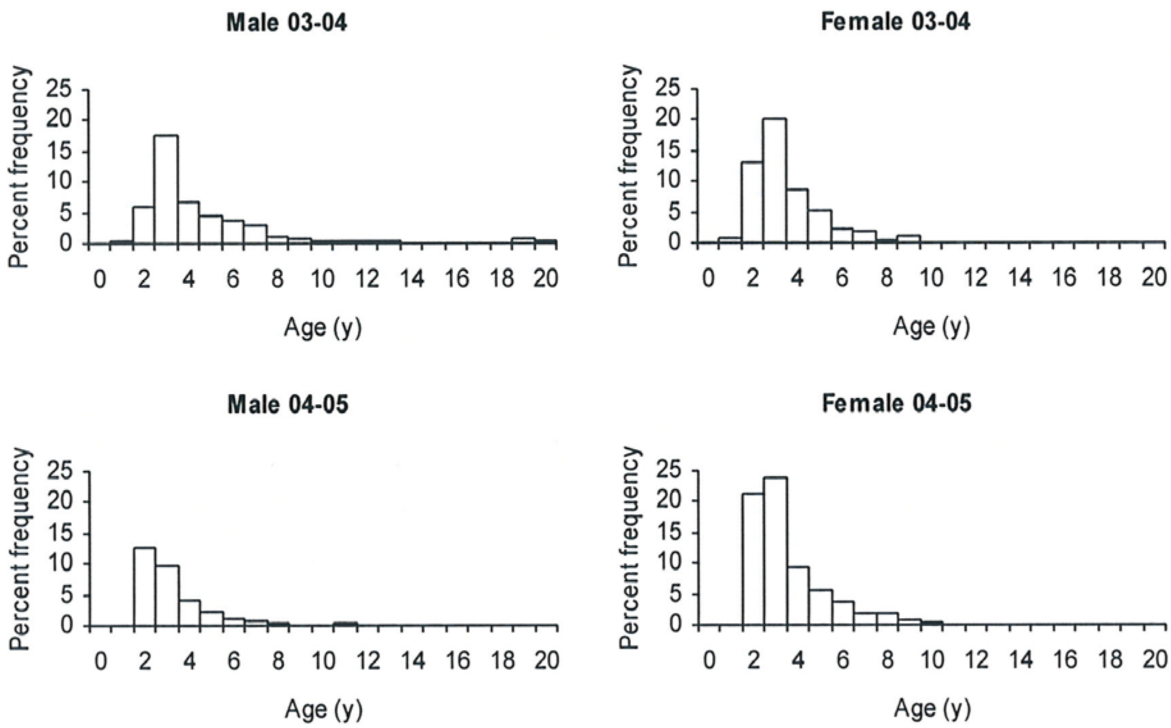

Figure 24: Scaled age distributions of male and female red gurnard from 2003–04 and 2004–05 bottom trawl fisheries in GUR 2 from Horn et al. (2006).

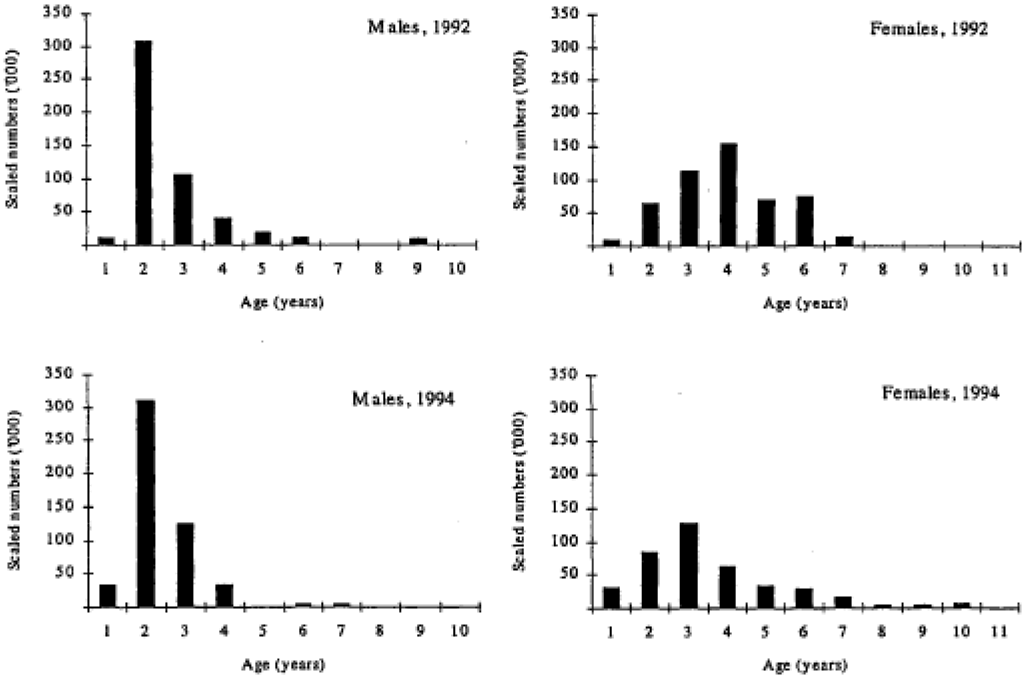

Figure 25: Scaled age distributions of male and female red gurnard from bottom trawl surveys in the Hauraki Gulf from Hanchet et al. (2000).

5. RECOMMENDATIONS FOR FUTURE CATCH SAMPLING PROGRAMMES

Optimisation of the number of sampled landings and the number of otoliths read per sample showed that increasing the number of landings sampled decreased the MWCV much faster than increasing the number of otoliths read per landing (Table 5). However, typically the main cost in sampling is staff time and logistics required to take a sample (though this constraint may be different in different situations). Therefore, if a desired MWCV is 0.20, then this may be achieved most effectively by reading 100 otoliths from each of 20 landings, but may also be accomplished by reading 30 otoliths from each of 30 landings, or even 10 otoliths from each of 60 landings.

Table 5: Estimated MWCVs for GUR 2 age composition as a function of the number of otoliths read per landing (columns) and the number of landings sampled (rows) based on samples from the 2009–10 market samples.

	Otoliths read per sample									
Landings	10	20	30	40	50	60	70	80	90	100
10	0.4442	0.3751	0.3424	0.3280	0.3144	0.3053	0.2989	0.2955	0.2897	0.2829
20	0.3270	0.2750	0.2485	0.2334	0.2266	0.2171	0.2151	0.2074	0.2059	0.2051
30	0.2702	0.2236	0.2000	0.1893	0.1835	0.1748	0.1742	0.1699	0.1691	0.1614
40	0.2376	0.1918	0.1766	0.1646	0.1592	0.1546	0.1506	0.1446	0.1441	0.1450
50	0.2109	0.1733	0.1574	0.1470	0.1403	0.1380	0.1353	0.1313	0.1315	0.1272
60	0.1955	0.1594	0.1431	0.1351	0.1309	0.1240	0.1232	0.1205	0.1201	0.1165
70	0.1797	0.1458	0.1326	0.1248	0.1177	0.1131	0.1129	0.1119	0.1105	0.1099
80	0.1662	0.1345	0.1250	0.1173	0.1125	0.1079	0.1057	0.1030	0.1048	0.1022

The optimal strategy will depend on other constraints within the sampling programme. For example, as discussed above, the requirement to collect enough samples for a robust estimation of the length at age relationship by sex and potentially by stratum may require more samples, as could the robust estimation of age and length at maturity given that appropriate samples may only be available for certain periods of the year. It is important that all the information required by the sampling programme be specified prior to considering the sampling strategy based on the desired precision of the age composition, as the most constraining information may not be age composition.

In addition, achieving these MWCVs is dependent on future samples showing the same variance structure as the 2009–10 fishing year. Therefore, some caution is advisable in relying on the sampling tactic to produce an exact MWCV and a somewhat lower MWCV than necessary should be targeted.

6. ACKNOWLEDGMENTS

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Appendix 1. Age composition and MWCVs for spring-summer and autumn-winter *post hoc* stratification of 2010 catch sampling.

A. Spring - Summer

Age	Male	Female	Total	Male_cv	Female_cv	Total_cv
0	0	0	0	NA	NA	NA
1	3 228	3 045	6 273	0.97	0.86	0.65
2	108 852	102 291	211 143	0.29	0.22	0.17
3	128 318	172 704	301 022	0.19	0.21	0.12
4	86 521	116 030	202 551	0.42	0.17	0.15
5	45 344	47 521	92 865	0.33	0.29	0.17
6	17 477	25 799	43 276	0.45	0.36	0.26
7	10 022	4 152	14 174	0.64	0.74	0.50
8	2 660	5 424	8 084	0.89	0.63	0.55
9	9 307	755	10 062	0.66	1.45	0.62
10	7 017	1 459	8 476	0.86	1.00	0.72
11	0	785	785	NA	1.49	1.49
12	0	1 543	1 543	NA	0.99	0.99
13	755	0	755	1.42	NA	1.42
14	4 581	0	4 581	1.41	NA	1.41
15	0	0	0	NA	NA	NA

B. Autumn-Winter

Age	Male	Female	Total	Male_cv	Female_cv	Total_cv
0	0	0	0	NA	NA	NA
1	43 825	48 139	91 964	0.36	0.56	0.29
2	141 826	146 101	287 928	0.41	0.23	0.16
3	82 510	117 667	200 176	0.26	0.26	0.19
4	57 037	39 835	96 871	0.32	0.36	0.24
5	48 021	27 743	75 764	0.36	0.46	0.26
6	19 385	9 700	29 085	0.54	0.69	0.46
7	14 495	269	14 764	0.88	1.44	0.86
8	0	1 003	1 003	NA	1.48	1.48
9	2 538	1 003	3 541	1.43	1.50	1.07
10	0	269	269	NA	1.50	1.50
11	0	3 308	3 308	NA	1.07	1.07
12	0	0	0	NA	NA	NA
13	0	0	0	NA	NA	NA
14	0	0	0	NA	NA	NA
15	0	0	0	NA	NA	NA

C. Pooled

Age	Male	Female	Total	Male_cv	Female_cv	Total_cv
0	0	0	0	NA	NA	NA
1	47 053	51 184	98 237	0.35	0.53	0.28
2	250 678	248 393	499 071	0.27	0.15	0.12
3	210 827	290 371	501 198	0.15	0.16	0.11
4	143 557	155 865	299 422	0.28	0.15	0.13
5	93 365	75 264	168 629	0.25	0.25	0.15
6	36 862	35 499	72 361	0.35	0.32	0.24
7	24 517	4 421	28 938	0.58	0.70	0.48
8	2 660	6 427	9 086	0.89	0.57	0.51
9	11 846	1 757	13 603	0.60	1.04	0.55
10	7 017	1 728	8 746	0.86	0.86	0.69
11	0	4 093	4 093	NA	0.92	0.92
12	0	1 543	1 543	NA	0.99	0.99
13	755	0	755	1.42	NA	1.42
14	4 581	0	4 581	1.41	NA	1.41
15	0	0	0	NA	NA	NA