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Review of Bay of Plenty trawl survey time series (1983–99)

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Report title: Review of Bay of Plenty trawl survey time series (1983–99)

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Executive Summary:

A time series of six trawl surveys was conducted off the Bay of Plenty from 1983 to 1999. This report reviews the time series and provides analyses of trends in relative abundance, catch distribution, population length frequency, and reproductive status of the major species. Detailed methods are provided for the survey design, trawling procedure, processing of the catch and analysis of data. The nature of the fishery, as well as the bathymetry and hydrology of the Bay of Plenty, are described.

The most consistently abundant commercial species on all six surveys were snapper, red gurnard and the jack mackerel *Trachurus novaezelandiae*. Following these were John dory and leatherjacket. Other species were present in lower abundance, including skates, tarakihi, and trevally.

Snapper was the main target species until the 1999 survey. Coefficients of variation (c.*v*.s) on total snapper biomass ranged from 10–21%. For 1+ and 2+ year classes, biomass *c.v.*s ranged from 24–78%, and 19–29%, respectively. *C.v.*s for other target species juvenile year classes were red gurnard 1+, 19–88%; 2+, 26–56%; John dory, 1+ 13–29%; trevally 1+, 47–100%; leatherjacket 1+, 30–50%; jack mackerel (*T. novaezelandiae*) 0+, 37–99%; 1+, 31–93%; 2+, 57–89%. Year class strength data from this series are currently not used in stock assessments for these species.

No statistically significant trends were found in pre-recruited, recruited or year class biomass for any species apart from snapper which were found to have increased greatly in abundance between 1983 and 1999, with the main increase occurring between the 1985 and 1990 surveys.

Distribution of each species was described, length frequency modes (potential year classes) were identified, and evidence of modal progression was noted. The relative proportions of gonad stages were summarised for female snapper for the 1990–99 surveys, along with male and female red gurnard, John dory and tarakihi sampled during the 1999 survey.

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Objectives:

See attached draft technical report.

Methods:

See attached draft technical report.

Results:

See attached draft technical report.

Conclusions:

See attached draft technical report.

Publications:

Draft technical report.

Data Storage:

Not applicable.

Review of Bay of Plenty trawl survey time series (1983–99)

Abstract

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Snapper was the main target species until the 1999 survey. Coefficients of variation (c.v.s) on total biomass ranged from 10–21%. For 1+ and 2+ year classes, biomass c.v.s ranged from 24–78%, and 19–29%, respectively. Coefficients of variation for other target species juvenile year classes were red gurnard 1+, 19–88%; 2+, 26–56%; John dory, 1+ 13–29%; trevally 1+, 47–100%; leatherjacket 1+, 30–50%; jack mackerel (*T. novaezelandiae*) 0+, 37–99%; 1+, 31–93%; 2+, 57–89%. Year class strength data from this series are currently not used in stock assessments for these species. Coefficients of variation on total biomass for these species were as follows; red gurnard 10–22%, John dory 12–44%, trevally 19–50%, leatherjacket 16–39%, and jack mackerels 19–96%.

No statistically significant trends were found in pre-recruited, recruited or year class biomass for any species apart from snapper. Snapper were found to have increased greatly in abundance between 1983 and 1999, with the main increase occurring between the 1985 and 1990 surveys.

Distribution of each species was described, length frequency modes (potential year classes) were identified, and evidence of modal progression was noted. The relative proportions of gonad stages were summarised for female snapper for the 1990–99 surveys, along with male and female red gurnard, John dory and tarakihi sampled during the 1999 survey.

The time series was found to provide valuable information on a range of species, especially juvenile snapper, and juvenile and adult red gurnard and John dory. Information returns on tarakihi were limited, possibly due to the survey timing coinciding with aggregation outside the survey area for spawning.

Introduction

Background

A time series of summer/autumn (February-March) trawl surveys was conducted in the Bay of Plenty from 1983 to 1999; for the purposes of this review, defined as the area falling between Mercury Island (Coromandel) to Cape Runaway, in water depths of 10–150 m, excluding estuarine areas. Since 1996, deeper strata of 150–250 m were also added, in order to target tarakihi. Surveys have been completed at 2 to 5 year intervals over this period.

There have been six trawl surveys; 1983, 1985, 1990, 1992, 1996, 1999 (Trip Codes – KAH8303, KAH8506, KAH9004, KAH9202, KAH9601, and KAH9902). A survey was also undertaken in 1987 (KAH8711), but is not included in this review as it was undertaken in October. Snapper, red gurnard and John dory were the primary target species up until 1996, when tarakihi was also added. Snapper was dropped as a target species in 1999.

Most of these surveys have been documented in stand alone reports with little comparison of the results between surveys (Drury & McKenzie 1992, Drury and Hartill 1993, Morrison 1997, Morrison & Parkinson 2000), although Langley (1994) provided a general overview of results for species other than snapper from the Auckland Fisheries Management Area (AFMA) trawl surveys. No reports were completed for the 1983 or 1985 surveys. This report reviews the time series of surveys and provides analyses of trends in relative abundance, catch distribution, population length frequency, and reproduction of the major species.

The Quota Management System was introduced in 1986 and many TACCs were set substantially below annual catches at that time to allow stocks to rebuild. There was no method of determining the sustainability of these TACCs and trawl surveys were initiated as a monitoring tool, providing stock assessment data such as relative biomass, population age and length frequency, that could be used to assess the sustainability of some key fisheries. From the beginning, the Bay of Plenty trawl survey series had a primary objective of determining the relative year class strengths of juvenile snapper (*Pagrus auratus*). However, it was found during modelling of the Hauraki Gulf/Bay of Plenty stock that trends in snapper recruitment were very similar between the two areas; subsequently estimation of snapper year class strength was limited to the Hauraki Gulf surveys, and in 1999 snapper was dropped as a target species.

John dory (*Zeus faber*) and red gurnard (*Chelidonichthys kumu*) are an important bycatch of the inshore trawl fisheries of this area, and have been important target species for monitoring as part of the trawl survey series. From 1996 onwards, tarakihi (*Nemadactylus macropterus*) was added as a target species. Other species for which information has been collected include jack mackerels (mainly *Trachurus novaezealandiae*), leatherjacket (*Parika scaber*), rough skate (*Raja nasuta*), and trevally (*Pseudocaranx dentex*).

The survey area has been consistent from year to year, although the stratification has been modified over time to improve survey performance for the target species. The 1983 and 1985 surveys included a 150–300 m stratum; in 1990 and 1992 these deeper areas were dropped. Deeper strata were added again for the 1996 and 1999 surveys to target tarakihi, covering the 150–250 m depth. Snapper was dropped as a target species in 1999, resulting in a substantial shift of station allocations from shallower to deeper strata, to improve the precision of the tarakihi biomass estimate.

The wording of Project Objectives has varied slightly between surveys, as has the objective emphasis, but can be represented as follows (based on 1999 survey – note the change in target species described above):

1. To determine the relative abundance and distribution of John dory, red gurnard, and tarakihi in the Bay of Plenty by carrying out a trawl survey. The target coefficients of variation (*c.v.*'s) of the biomass estimates for these species were as follows: John dory (20%); red gurnard (15%); tarakihi (30%).

2. To collect the data and to determine the length frequency, length-weight relationship and reproductive condition of John dory, red gurnard, snapper and tarakihi.

3. To collect otoliths from John dory, red gurnard, snapper and tarakihi.

4. To collect the data to determine the length frequencies of all other Quota Management System (QMS) species, and frostfish (*Lepidopus caudatus*), leatherjacket (*Parika scaber*), kahawai (*Arripis trutta*) and kingfish (*Seriola lalandi*).

Prior to the 1999 survey, only limited reproductive information was collected for female snapper, and no length-weight data were collected for any species. During the 1999 survey, reproductive information and length:weight data were collected for red gurnard, John Dory and tarakihi, as well as snapper.

Bay of Plenty Fishery

The Bay of Plenty has large areas of foul ground that are unavailable for trawling. The area of trawlable ground within the survey area is 6 210 km^2. Most of the commercial snapper catch (49%) is caught by single trawl, with a further 30% by Danish seine (Walsh *et al.* 2000). The remainder is caught by long-lining and pair trawl. Total snapper tonnage taken in 1999–00 was about 1 350 t.

Red gurnard are taken as a bycatch of the snapper and tarakihi fisheries in the Bay of Plenty (Hanchet *et al.* 2000), while John dory are taken as a bycatch of the snapper and trevally fisheries (Annala *et al.* 2000). Target fishing of John dory has however increased since 1990 (Annala *et al.* 2000). No published figures are available for the catch of these two species on a finer scale than that of GUR 1E and JDO 1E respectively (east coast components of GUR 1 and JDO 1 – see Horn *et al.* 1999, Hanchet *et al.* 2000).

Trevally are also a target species in the Bay of Plenty; in 1998–99 384 t were taken by single trawl, with a further 173 t by purse seine (Cameron Walsh, pers. comm.) Figures for pair trawl are not available. Trawling is also undertaken for tarakihi, with 329 t being landed from the Bay of Plenty region in 1999-00 (Field, *in prep.*).

Hydrology and bathymetry of Bay of Plenty

The bathymetry of this region consists of a sloping continental shelf, with large areas of foul ground spread throughout the survey area. Detailed hydrology and sediment work has been mainly confined to the coastal fringe, in particular Tauranga Harbour and surrounds, which has attracted attention as the major port in the region, and as the largest harbour system present (Hume *et al.* 1992). Ridgway and Greig (1986) found the mean flow of water through the Bay of Plenty to run from west to east, as part of the East Auckland Current.

Methods

Survey area and design

The survey area (Figure 1) has been relatively constant from survey to survey, covering the 10–150 m depth range from the Mercury Islands to Cape Runaway. The 1983 and 1985 surveys also included a 150–300 m stratum, which was dropped for the 1990 and 1992 surveys. For the 1996 and 1999 surveys, deeper strata (150–250 m) were added to target tarakihi. Snapper was dropped as a target species in 1999, resulting in a substantial shift in sampling effort from shallower to deeper strata (to reduce tarakihi c.v.s).

Surveys were of a two phase stratified random design (*after* Francis 1984). Trawls were conducted at randomly selected positions (generated within the software Rand_stn version 1.7), at least 2 n. miles (3.7 km) apart. Allocation of stations was based on stratum area and previous target species catch rates, with a minimum of 3 stations per strata. Phase 2 stations were allocated to improve the biomass indices of the target species. This was achieved by adding a station iteratively to each of the strata, and using the existing density and variance information to predict the likely improvement in the individual species c.v.s, for each possible stratum allocation. The station was then assigned to the stratum giving the greatest improvement across all c.v.s, and the process repeated until all stations available had been allocated.

Vessel and gear specifications

RV *Kaharoa*, a 28 m stern trawler with a power rating of 522 kW and a displacement of 302 t, is capable of trawling to depths of 500 m. All trawling was carried out using a high opening bottom trawl (HOBT), with cut away lower wings and a nominal 40 mm codend.

Trawling procedure

Trawling procedure was standardised for all surveys. Tows were conducted in daylight between 0530 and 1700 hours (NZST). If the station was in an area of foul or the depth was out of range, an area within 2 n. miles (3.7 km) of the station in the same stratum was searched for suitable ground. If suitable ground was not found, the station was abandoned and the next station on the list was selected as a replacement. Standard tows were 0.7 n. miles (1.3 km) for shallower stations and 1 n. mile (1.85 km) for deeper stations. This difference in tow length was adopted to allow for higher catches in the shallower strata. Distance was estimated using GPS, and/or satnav or radar for earlier surveys.

Kaharoa was equipped with Scanmar for the 1999 survey, and doorspread was recorded and averaged over the tow. Headline height was recorded from the netsonde and averaged over the length of the tow. Prior to 1996, the method of Kawahara and Tokusa (1981) was used for estimation of door-spread, using the spread of the warps as a surrogate for door-spread (*see* Langley 1994). Summaries of gear performance parameters are given in Appendix 1.

Sea bottom temperature was recorded from a net sonde prior to the 1999 survey, when SCANMAR was available. Sea surface temperature was recorded with a hull-mounted sensor prior to 1996; subsequent to this measurements were taken using a manually lowered bucket.

Catch and biological sampling

The catch from each tow was sorted by species, boxed, and weighed on motion-compensating 100 kg Seaway scales to the nearest 0.1 kg. Length, to the nearest centimetre below actual length, and sex were recorded for ITQ and selected non-ITQ species, either for the whole catch or, for larger catches, on a sub-sample of up to 200 randomly selected fish. Biological information was collected from a random sample of up to 60 fish for snapper. One or more of the following records or samples were taken: length to the nearest cm below actual length, otoliths, sex and gonad stage (females only). In the 1996 and 1999 surveys, otoliths were also collected for red gurnard, John dory and tarakihi. In the 1999 survey, sex and gonad stages were recorded from samples of these species (for staging keys, see Appendices 3–6).

During the 1999 survey, length-weight data were collected for snapper, red gurnard, John dory and tarakihi, and regressions calculated. Length-weight data was not collected in earlier surveys.

Analysis of data

Doorspread biomass estimates were based on the area-swept method described by Francis (1981, 1989) using the Trawlsurvey Analysis Program (Vignaux 1994). Biomass estimates for surveys prior to 1996 used doorspread values estimated using the method described by Kawahara & Tokusa (1981). Subsequent to the 1992 survey, SCANMAR was available. For those stations where SCANMAR data were not available, an average from those where it was available for the appropriate depth range was substituted. For all surveys, all tows where the gear performance code was 1 or 2 were used for biomass estimations (these codes indicate that the trawl worked well, without problems that could influence catch rates). The relative biomass estimates assume that: the area swept on each tow equals the distance between the doors multiplied by the distance towed; that all fish within the volume swept are caught and there is no escapement; that all fish in the water column are below the headline height and available to the net; that there are no fish from the Bay of Plenty stocks outside the survey area at the time of survey; and that fish distribution over foul ground is the same as that over trawlable ground (though for the Bay of Plenty, most foul ground is excluded from biomass calculations, through exclusion from the strata areas).

Species were chosen for analysis based on the criterion that a minimum total of 200 kg was caught on at least half of all surveys and at least 100 kg caught on other surveys in the series. All length frequencies were scaled by the percentage of catch sampled, area swept, and stratum area using the Trawlsurvey Analysis Program. Length-weight coefficients used to scale length frequencies and calculate biomass by length calculations are given in Appendix 2. Biomass estimates were calculated for both the 10–150 m depth range, and for the 150–250 m strata for the 1996 and 1999 surveys.

Linear regression analysis was used to examine whether trends in biomass were statistically significant using the computer programme Excel 97™ for Windows. The slope of the regression was considered to be significantly greater than zero if $P < 0.10$.

Results

Stations surveyed

The number of stations completed overall in each survey has ranged from 63–89 (Table 1). For the first five surveys (1983–96), sampling effort was concentrated in shallower strata to target snapper. In the 1999 survey, sampling intensity shifted towards deeper strata to improve the *c.v.* for tarakihi biomass.

Biomass and precision

Biomass estimates and coefficients of variation for the 9 main commercial species are given in Table 2, for the 10–150 m strata, and for 1996 and 1999 the 10–250 m strata. Snapper were the dominant species in terms of biomass from 1990 onwards; prior to this biomass was relatively low. Biomass indices for red gurnard and John dory were relatively consistent throughout the time series, while leatherjackets, terakihi and trevally were more variable. Jack mackerel biomass was very variable through time, but it is likely that this species varies in its vulnerability to the trawl, occurring at a range of heights above the sea-floor.

The coefficient of variation (c.v.) is an indication of the precision of the biomass estimate. For the three traditional target species, c.v.s on total biomass were generally acceptable; snapper 10–21%, red gurnard 10–22%, John dory 12–24%. Contributions to biomass from the 150–250 m strata were generally insignificant (<1–4%).

Tarakihi biomass was less well estimated, with c.v.s of 46 and 27% for the 1996 and 1999 surveys respectively (10–250 m strata). For the 10–150 m strata (1983–99), *c.v.*s were also generally high (39–98%). One of the problems with sampling this species precisely in 1996 and 1999 was a low level of historical sampling in the deeper strata, making accurate delineation of areas of higher and lower abundance problematic. However, the high allocation of stations to deeper strata during the 1999 survey (in particular strata 7026) will allow this issue to be addressed in any future trawl survey of the Bay of Plenty. The addition of deeper strata (150–250 m) in the 1996 and 1999 surveys did not result in substantive increases in total biomass estimates of tarakihi.

For non-target species, c.v.s were generally high; jack mackerels (*T. novaezealandiae, T. declivis*, "generic") 26–96%, rough skate 28–87%, trevally 19–50%, and leatherjackets 16–39%.

Estimates of year class strength are given in Table 3. For snapper, c.v.s for 1+ fish ranged from 24–78%, 2+ fish from 19–29%; red gurnard 0+ from 19–88%, 1+ from 25–56%; John dory 1+ from 14–29%. No juvenile tarakihi were sampled, suggest recruitment from another area. The *c.v.*s of juvenile year classes of non-target species were; jack mackerels 31–99%, leatherjacket 21–50%; trevally 1+, 47–100%, 2+ 52–100%.

It is important to note that optimisation of station allocations for this trawl series has been made using the individual catch weights of one or more of the 3 to 4 target species (snapper, red gurnard, John dory and tarakihi); c.v.s for other species, or age classes of species, could be substantially improved if selected as target species for the survey.

Biomass trends

Trends in recruited and total biomass for the 5 main commercial species are shown in Figure 2. No trends in increasing or declining biomass were detected for any of these species apart from snapper, which showed significant increases at the 10% significance level (for both recruited and total biomass). Estimated trevally biomass increased six-fold between the 1996 and 1999 surveys; this increase seems too large to be accounted for by growth and recruitment alone, and suggests a change in availability. Correlations between water temperature and catch rates have been shown previously for this species (Langley 1994).

Tarakihi showed marked fluctuations in biomass between years, also suggesting differing annual availability to the sampling gears. This could be caused by a seasonal shift in abundance between shallower and deeper waters, which may be temporally variable from year to year. However, an alternative explanation may be that of simply poor biomass estimation, given the high associated c.v.s.

Red gurnard biomass was very low during the 1985 survey (only 18% of the next lowest biomass estimate), an anomaly that cannot be readily explained and does not appear to be a result of true changes in stock abundance.

Only snapper and red gurnard had relatively high proportions of pre-recruit biomass in the survey area (Figure 2)

Distribution and length frequency

The distribution and size of catches expressed by catch rates (kg.km^{-2}) for major species are shown in Figure 3 and length frequency distributions in Figure 4.

Jack mackerels

Jack mackerels were not always properly identified down to species (*T. novaezelandiae* or *T. declivis*) for the first five surveys, with the generic code "jack mackerel" being used for 15–100% of the total catch. This makes meaningful interpretation of data at the species level difficult. Jack mackerel were caught at between 50% and 67% of stations (Figure 3a–c).

Jack mackerels were distributed throughout the survey area during the 1983-85 surveys, but were uncommon in the 1990 survey, being caught mainly in the southwest of the survey area (Figures 3a–c). In the 1992, jack mackerels were mainly caught at shallower stations, particularly in the southwest, while in 1996 survey catch rates were more widespread. In 1999 (the only survey where all mackerel catch were identified down to species), *T. novaezelandiae* was patchily distributed throughout the survey area, with consistently higher catches in the southwest of the study area (Figure 3a), while *T. declivis* was caught in lower abundance at deeper stations only (Figure 3b).

Length frequency data were dominated by immature fish, with only small numbers of fish over 20 cm being sampled (Figures 4a–b). Juvenile modes were present in the 5–10 and 10–20 cm range, depending on the year of survey, for both species. These modes were likely to represent 0+ and 1+ cohorts.

John dory

John dory were distributed throughout the survey area and were caught at 62–84% of stations (Figure 3d). In 1992 consistently higher catch rates were taken in the eastern half of the survey area. This trend appeared to persist through the 1996 and 1999 surveys, albeit less markedly.

Length frequencies were generally composed of two modes, one around 20–30 cm (likely to be 1+ fish) and one around 30–45 cm (up to 50 cm for females) (Figure 4c). Few fish less than 20 cm were sampled.

Leatherjacket

Leatherjackets were common in all surveys, occurring predominantly in the eastern half of the survey area (Figure 3e), at depths of less than 100 m. This abrupt drop in abundance from west to east seems unusual; it does not mark the southern extent of this species, which occurs in abundance further down the coast. Changes in bottom habitat might have caused this pattern, but no detailed data is available against which to compare catch rates. Leatherjacket occurred at 44–67% of stations.

Length frequencies for this species were composed of fish of 15 cm or greater, with a consistent mode present across all surveys of 20–30 cm fish (Figure 4d). A mode of smaller fish (15–20 cm) was sampled in the 1992 survey, possibly representing a large recruitment event.

Red gurnard

Red gurnard were found throughout the survey area, occurring at 60–100% of stations (Figure 3f). Catch rates were generally higher in the shallower strata, but no consistent spatial patterns were apparent. Catch rates were very low during the 1985 survey compared to all other surveys, with biomass being only 18% of that of the next lowest biomass estimate in the series.

Length frequencies were dominated by fish in the 20–40 cm range for both males and females, with smaller modes of male fish of 10–20 cm in the 1983, 1990 and 1999 surveys (Figure 4e). Females in general appeared to grow to a larger maximum size than males (~50 cm versus ~45 cm).

Rough skate

Rough skate were caught at 5–30% of stations (Figure 3g). Identification of skate down to the species level was not made during the 1990 survey, while none were caught in 1992. Across all surveys, catch rates were modest; the limited spatial resolution available suggested that fish were more common in the deeper strata in 1985, 1996 and 1999. The 1983 survey was an exception to this pattern, with small catches also being made at several shallower stations.

Too few fish were caught and measured on each survey to show clear modes in the length frequency distributions (Figure 4f). However, smaller fish were present in the 1983 survey (presumably juveniles).

Snapper

Snapper were caught at 75–97% of stations (Figure 3h). Catches were highest in the shallower strata, especially in the 10–25 m depth range. Higher relative catch rates were consistently found immediately offshore of Tauranga Harbour, apart from the 1999 surveys, when few stations were sampled in this region (as snapper was not a target species). Few snapper were caught in the 150–250 m strata sampled in 1996 and 1999.

Length frequency data showed a consistent mode of fish in the 20–35 cm range from 1985 onwards; prior to this numbers were low (Figure 4g). Substantive recruitment modes were sampled in 1990, 1992 and 1996.

Tarakihi

Tarakihi were uncommon within the general survey area for all surveys (Figure 3i). Even in 1996 and 1999, where the deeper strata were added to specifically target this species, few were caught, and they were absent from many of the deeper stations. It appeared from the 1996 and 1999 surveys that fish were present in the northwest and southeast deeper areas, but were absent from the central deeper area (although this zone of zero catch rate appeared to shift spatially between the two surveys).

Length frequency data showed the sampled population to be composed of fish mainly 25–40 cm in length, with very few juvenile fish (less than 20 cm) being present (Figure 4h). Larger numbers of fish were sampled during the 1985 and 1992 surveys (with correspondingly higher biomass estimates), the reasons for which are unknown. These numbers came from higher catches within a number of limited stations, rather than a higher proportion of stations containing tarakihi relative to other surveys.

Trevally

Trevally were distributed throughout the shallower strata and were caught at 21–62% of stations (Figure 3j). The 1983 survey was notable for a very low occurrence of trevally. Trevally were consistently common around the vicinity of Tauranga and Ohiwa harbours. In 1999 fish were also caught in deeper strata on the western side of the survey area.

Length frequency data showed a wide range of sizes to be present all surveys (Figure 4i). Only the 1990 survey displayed a clear mode of juveniles, from 15–23 cm. Most fish were in the 30–45 cm range. Few fish less than 15 cm were sampled, although a few individuals of this size were measured in 1983, 1990 and 1999.

Reproductive condition

Data on female snapper gonad stage were collected only for the 1990–99 surveys (Table 5). Snapper female gonads were mainly in the resting and developing phase. For the 1999 survey, all three target species (red gurnard, John dory and tarakihi) were sexed and staged (Table 6). Appropriate staging keys for all target species are given in appendices 3–6.

Red gurnard females were mainly previtellogenic/regressed or vitellogenic, with a small proportion being mature. Most males were spermatogenic to partially spermiated. John dory males were mainly in a developing state, while males were mainly developed or gravid. Tarakihi males and females were mainly in a developing state.

Discussion

The usefulness of trawl survey time series depends on a number of factors including the length of the time series, the variability of the survey indices, the availability and catchability of the stock to the survey technique and the availability of appropriate stock assessment models to utilise the data. The information obtained from the trawl survey series could be formally assessed using a quantitative approach such as that advocated by Cordue (1998). However, for the target species of this survey there are no current stock assessments which could easily be used to evaluate the time series. Instead, other less formal ways of identifying the benefits need to be investigated.

Recommendations on the usefulness of undertaking future trawl surveys in the Bay of Plenty are addressed by considering the following questions

- Does the survey design adequately cover the known distribution of the fish?
- Are the levels of precision adequate to monitor trends in biomass?
- Are there any significant trends in biomass and how might they be interpreted?
- Have there been trends in the spatial patterns of the species abundance?
- How do changes in abundance indices from the trawl surveys compare with other available estimates of abundance?
- Are there trends detectable in the fish size frequency and age composition data?
- Are the trends in age composition data from the trawl surveys consistent with age composition data from shed sampling?

- What frequency of surveys would be required to monitor the biomass of the key species through time?
- What are the benefits of developing time series of age data from any of the key species?

The focus of this work was on the target species snapper, red gurnard, John dory and tarakihi.

Snapper

The SNA1 QMA includes the east coast from North Cape down to East Cape. The Bay of Plenty trawl survey boundaries cover the area from Great Mercury Island across to East Cape. The Hauraki Gulf component of the stock is surveyed regularly using trawl surveys (e.g., Morrison & Francis 1999), while the remaining area (East Northland) has been surveyed in the past, but the series was discontinued due to insufficient information returns. The Bay of Plenty and Hauraki Gulf substocks are currently modelled as one entity (Davies *et al.* 1999), but there is some discussion about future modelling of the two stocks separately (Gilbert 1999).

During the series, snapper were more abundant in shallow water stations (less than 50 m water depth). This was consistent with the more general finding that snapper are most commonly caught in inshore waters of northern New Zealand, with rapidly declining catch rates with increasing water depth, down to a maximum of about 200 m (Anderson *et al.* 1998). There was no obvious spatial variation in catch rates between years. Examination of the relative catch rates of snapper showed consistently high catch rates around the general area of Tauranga Harbour, suggesting the potential for this harbour to be acting in a nursery capacity. Waters less than 10 m in depth were unable to be worked by the survey vessel, and snapper within this zone (along with estuarine waters) are not included in survey estimates.

Trawl survey year class strength estimates (expressed in this report as biomass) for 1+ and 2+ snapper have been variable over time; 1+, <1–26 t; 2+, 10–194 t. Associated c.v.s have also been variable; 1+, 24–78%; 2+, 19–29%. Currently, otoliths are collected from snapper during the surveys and archived. Survey design has been based on total catch weights of snapper; if more precise year class strengths were required in future surveys, then simulations based on catch rates of individual juvenile year classes would be more appropriate (although it should be noted that snapper is not currently a target species).

Gilbert (1999) analysed the difference in snapper year class strengths between the Hauraki Gulf and Bay of Plenty sub-stocks. He found broad agreement on strong and weak year classes, but the actual values did not match precisely. His conclusion was that the "current practise of treating Hauraki Gulf and Bay of Plenty as a single sub-stock for stock assessment purposes may not be entirely satisfactory". Shed sampling of commercial snapper landings from the two stocks have shown broad similarities in relative year class strengths and recruitment patterns between the SNA1 sub-stocks since 1989–90, particularly in extremely strong and weak year classes (Walsh *et al.* 1995, 1997, 1998, 1999). Strong 1989 and 1991 year classes were clearly evident in all sub-stocks, as were weak 1987 and 1992 year classes (Walsh *et al.* 2000). The strong 1994 year class was most evident in the Bay of Plenty, probably due to a faster growth rate (Walsh 1997).

Examination of the trawl survey biomass indices showed that for 2+ fish, the 1994 year class (sampled in KAH9601) was relatively strong, while the 1997 year class (sampled in KAH9902) was very strong (although these fish have not yet have recruited into the commercially harvested component of the stock). The trawl survey 1+ and 2+ abundance estimates cannot be compared directly, as they are based on fish weight (although they could be if calculated in terms of fish numbers). Processed otolith collections are available for the 1990, 1992 and 1996 surveys; collections do not appear to have been made for the 1983 and 1985 surveys, while in 1999 otoliths were collected and archived only. For the 1+ series, the 1989 year class was relatively strong, but the 1991 year class was only of modest strength. The 1995 year class was quite strong in the trawl series; this year class now comprises 25% of the commercial longline catch (Walsh *et al.* 2000), although it has not yet recruited fully into the fishery.

At the present time it is difficult to assess what the frequency of trawl surveys within the Bay of Plenty should be for juvenile snapper. Ideally some form of environmental-recruitment relationship would be developed for snapper similar to that used in the Hauraki Gulf, so that trawl surveys could be targeted at predicted strong or weak year classes to further improve the robustness of such a relationship (Annala *et al.* 2000). Currently, recruitment indices generated from the Hauraki Gulf trawl survey time series are considered to be analogous with those expected in the Bay of Plenty sub-stock, and are used as such *i.e.*, the Bay of Plenty trawl survey data is not used in formal stock assessments. However, the validity of this assumption has recently been questioned (Gilbert 1999). In the absence of a surface water temperature – snapper recruitment model for the Bay of Plenty (and to possibly enable one to be developed in the future), the current regime of surveys at two to five year intervals should be changed to a biennial status. This would provide an estimate of year class strength for all recruiting fish, as either 1 or 2 year olds. It is critical to continue to collect adequate numbers of otoliths during each survey to generate good age-length keys, as lengths-at-age have been shown to change between years, perhaps due to interannual changes in growth rates (Walsh 1997).

Red gurnard

The GUR1 QMA includes the west coast of the north island down to the Taranaki Bight, up around North Cape, and down to East Cape. During the surveys, red gurnard were caught throughout the survey area, although catch rates were lower in the deeper strata. Red gurnard are most commonly caught throughout New Zealand in waters less than 100 m depth (see Anderson *et al.* 1998), and the main fisheries operate in less than 100 m (MFish unpubl. data, quoted in Beentjes & Stevenson 1999). The minimum inshore water depth for the Bay of Plenty surveys is 10 m; gurnard in areas shallower than this are not included in survey estimates. The proportion involved is unknown but is unlikely to be large. All of the Bay of Plenty component of GUR 1 appears to be adequately covered by the current survey extent.

Total biomass estimates show no trends over the time series. Of note was an extremely low biomass estimate during the 1985 survey, which is likely to have been due to a change in catchability rather than a true change in stock abundance. CPUE indices calculated from commercial trawling for this species suggested that biomass in GUR 1E (see below for definition) declined in the early 1980s, and then recovered slightly in the 1990s.

Coefficients of variation tended to be good on total red gurnard biomass (10–22%), but were much higher for 0+ (19–88%) and 1+ (25–56%) fish biomass. As surveys were not optimised for particular age classes of red gurnard, these c.v.s could be improved upon in future surveys if required.

Juvenile size modes were present in the 10–20 cm length range in 1983, 1990 and 1999. Hanchet *et al.* 2000 recently completed a stock assessment for red gurnard for GUR 1 and GUR 2, with GUR 1 being divided up into west and east coast components (1W and 1E). In their assessment they used length data and otolith collections taken during trawl surveys in GUR 1, but in the case of 1E only included otoliths collected from the Hauraki Gulf (due to insufficient sample sizes being collected during the Bay of Plenty trawl surveys). Incorporation of proportion-at-age and estimates of 1+ recruitment from the Hauraki Gulf improved the assessment for GUR 1E by producing a better fit to the abundance estimates. They stated that "it appears likely that a continuation of these trawl survey series (including the associated proportion-at-age data) will improve further assessments." While this statement was made with respect to GUR 1W and data from the Hauraki Gulf component of GUR 1E, it appears likely this conclusion would also hold for the Bay of Plenty component of GUR 1E. In the most recent survey of the Bay of Plenty (KAH9902), 278 red gurnard otoliths were collected (compared to modest or no collections in earlier surveys). Sample sizes in future trawl surveys should be maintained around this level, which should be sufficient to generate proportion-at-age for the species for any future stock assessments. The frequency of surveys should be matched to the number of age classes that can be meaningfully assigned year class strengths; e.g., if three class strengths could be estimated from a survey (say 1+ and 2+), then triennial surveys would be sufficient to estimate year class strength for all years.

John dory

The JDO 1 QMA extends from Tirua Point on the west coast up around North Cape and down and across to East Cape. The survey boundaries cover the Bay of Plenty component of this area. As for the other species examined in this report, that proportion of the stock in less than 10 m, or in estuarine areas, was not accessible to the surveys.

During the series John dory were caught throughout the survey area, however there was some indication of higher abundance in the western half of the survey area in some years (1992, 1996, 1999). Depth did not appear to exert a strong influence on catch rates. John dory are most commonly caught in waters less than 250 m, with a steep decline in the proportion of tows in which it occurs as water depth increased (Anderson *et al.* 1998).

Total biomass index estimates were consistent between surveys (111–236 t), while c.v.s varied from 12–44%. For fish presumed to be 1+ in age, biomass was relatively constant (16–43 t), with associated c.v.s of 13–29%. Considerable uncertainty exists over the ageing of John dory, but examination of length frequency data by Horn et al. (1999), indicated a mean length of 20 cm at age 1 for both sexes, and an upper limit for 1+ fish of 32 cm for the Bay of Plenty. Above this size, age estimates remain difficult to determine.

The stock assessment for JDO 1 is currently separated into a west and east component (1W and 1E)(Horn et al. 1999). Estimates of 1+ relative abundance were calculated from trawl surveys (including the Bay of Plenty series), but the Inshore Working Group considered these indices to be based on unacceptably small sample sizes; subsequently they were excluded from use in the stock assessment model used. Due to a current inability to estimate year class strength, and therefore the necessity to assume average recruitment in all years, the stock assessment model for JDO 1E has poor model fits. Horn et al. (1999) state that it is "difficult to evaluate the usefulness of the two trawl survey series in assessments of JDO 1E until catch-at-age data are available" (referring to the Hauraki Gulf and Bay of Plenty trawl survey series); and that "the availability of year class strength data could greatly enhance the usefulness of the trawl survey indices of abundance, particularly as the apparent high productivity of John dory could result in marked fluctuations in biomass if its recruitment success is variable".

In summary, the trawl survey covers the south-eastern range of the JDO 1E population. The consistency of the biomass indices indicates a fairly stable population. Problems with ageing of this species need to be resolved, but likely estimates of maximum age are 4 or 8 years (Horn *et al.* 1999). Given the very stable biomass estimates over time, and the moderate levels of recruitment variation, trawl surveys every three years are probably sufficient to monitor JDO stocks. However, if estimates of year class strength are to be made, then surveys would need to be more frequent.

Tarakihi

The TAR 1 QMA includes the west coast of the North Island from Tirua Point up around North Cape and down and across to East Cape. Only the 1996 and 1999 surveys specified tarakihi as a target species, with strata covering the 150–250 m depth range being added to improve sampling coverage for this species. In general, catch rates for this species have been modest. Most fish are taken from deeper areas, but occasional catches were also made in the shallower strata. Tarakihi are most commonly caught in waters less than 500 m, with a maximum in the percentage of tows in which it is taken in around 250 m water depth (Anderson *et al.* 1998). Therefore the lower depth limit currently in use for the Bay of Plenty trawl series (250 m) is unlikely to fully encompass the stock boundaries for tarakihi in the Bay of Plenty. In addition, tarakihi may spawn outside of the survey area during the survey period, or be densely aggregated within small areas that may be missed during the survey. Tong & Vooren (1972) reporting them spawning off Motiti Island in the western Bay of Plenty mainly from January to April.

The highest biomass estimates were in 1985 and 1992, when the survey only sampled to a depth of 150 m water. Estimates of biomass ranged from 6–169 t for the 10–150 m strata (all surveys), with associated c.v.s of 39–98%; while those of the 10–250 strata ranged from 35–51 t, with associated c.v.s of 27–46% (1996 and 1999 surveys). These results suggest substantial differences between years in the depth availability of tarakihi to the trawl gear, or alternatively, patchiness in their distribution within strata. The biomass estimates are also very modest, given the commercial catch taken from the Bay of Plenty, which is in excess of 300 t. An analysis of commercial CPUE for the northeastern component of TAR 1 (East Northland and Bay of Plenty combined) from 1989–99 shows a slight decline from 1990 to 1993, following by a slight increase up until 1997–99 (Field, *in prep.*).

The size frequency of fish sampled was composed mainly of fish 25–40 cm in length, with very few juvenile fish (less than 20 cm) being present. This suggests that juveniles probably recruit in from other areas (as fish down to 10 cm or less should be susceptible to the sampling gear).

No recent stock assessment currently exists for this species.

Non-target species

Although the focus of the surveys was on the four target species (note snapper was dropped as a target species in 1999), other species were also examined to determine whether the survey is useful for monitoring their changes in abundance. In this analysis we have focussed mainly on the consistency of the biomass indices, the length frequency distributions between years, and on the precision of the indices (c.v.s).

Jack mackerels

The biomass of jack mackerel (*T. declivis*, *T. novaezealandiae*, and "generic") varied greatly through the surveys (0.4–10 t, 19–1 132 t, and 3–117 t respectively, for the 0–150 m strata). Associated c.v. ranges were 26–85%, 33–89%, and 28–96%. The degree of identification down to species level varied through the surveys. Variability in age class biomass estimates was high; *T. declivis* 0+ 0.1 t, c.v. 68%, 1+ 1.1 t, c.v. 68% (1983 survey only); *T. novaezealandiae* 0+ 0.2–58 t, c.v. 37–99%; 1+ 36–821 t, c.v. 31–93%; 2+ 52–224 t, 57–89%.

Size frequencies were dominated by juvenile fish, with only small numbers of fish over 20 cm being sampled. Juvenile modes were often present in the 5–10 and 10–20 cm range, depending on the year of survey, for both species.

Rough skate

Elasmobranches tend to be reasonably long lived with low recruitment variability and so would be predicted to have consistent biomass estimates between years. During the series, the biomass estimates of rough skate were consistently low (0–68 t), with associated c.v.s of 28–87%.

Little useful information appeared to be available in the length frequency data, due to the low number of individuals sampled.

Leatherjacket

Biomass estimates of leatherjacket were reasonably consistent at 271–413 t, apart from 1985 (46 t). Associated c.v.s were good at 10–22%. Variability in 1+ fish biomass was high, at ~0–127 t (c.v.s 21–50%). Juveniles of this species (less than 10 cm) are known to commonly recruit first to floating flotsam, then to reef associated brown algal fronds; hence they are unlikely to occur commonly in areas vulnerable to capture by research trawl.

Size frequencies were dominated by a mode of fish in the 20–30 cm range, but a large recruitment event was evident in 1992, centred around the 15–20 cm range, with modest numbers also occurring in 1996 and 1999. It should be noted that the depth distribution of shots has changed with a shift towards targeting tarakihi in deeper water and away from targetting snapper in shallower water. Given that the depth range of leatherjacket is restricted to waters of less than 50 m (Anderson *et al.* 1998), this is likely to have resulted in a reduction of the number of animals being sampled in more recent surveys.

Trevally

Biomass estimates of trevally were stable from 1983 to 1996, ranging from 6–90 t, with associated c.v.s of 19–50%. In 1999 a higher biomass estimate of 266 t (c.v. 26%) was derived.

Catches of 1+ trevally were negligible, while 2+ fish biomass ranged from 2.1–9.5 t, apart from the 1983 survey where only 0.2 t was estimated to be present. Associated c.v.s were high (52–100%). It is likely that the catchability of trevally may vary from year to year through influences from factors such as temperature and water clarity (Annala et al. 2000, Francis *et al.* 1999). Therefore recruitment indices should be regarded as uncertain. This uncertainty was allowed for in the stock assessment for this species (Hanchet 1999).

Conclusions and Recommendations

Snapper

- This species is currently not a target species (dropped in the 1999 survey), but data collected may still be useful to stock assessments for this species.
- The Bay of Plenty component of SNA 1 is adequately covered by the survey boundaries as they currently stand.
- Trawl survey year class strength estimates for 1+ and 2+ snapper probably track changes in actual recruitment strength reasonably well.
- These estimates are not currently an important input into the SNA 1 model, but it has recently been suggested (Gilbert 1999) that effort should be directed towards examining the separate modelling of the Hauraki Gulf and Bay of Plenty substocks of SNA 1.
- It is important to continue to collect and process snapper otoliths for each survey, to provide survey specific age length keys.
- If reinstated as a target species, future surveys should continue at at least two to three year intervals, to provide year class strength estimates for 1+ or 2+ fish.

Red gurnard

- The Bay of Plenty component of GUR 1 appears to be adequately covered by the current survey extent.
- The surveys appear to be monitoring both the pre-recruit and recruited components of the GUR 1E Bay of Plenty population.
- Proportion-at-age and 1+ estimates for the trawl series would allow the estimation of year class strength and could improve future assessments by allowing a better fit to the abundance indices for the Bay of Plenty. Sufficient otoliths need to be collected during trawl surveys for this purpose.
- An appropriate survey frequency for this species cannot be assessed until more stock modelling is carried out, but is likely to be at least every two to three years.

John dory

- It appears that the Bay of Plenty component of JDO 1 is adequately covered by the survey.
- Recruitment and total biomass appear to be relatively stable.
- The availability of year class strength data would greatly enhance the usefulness of the trawl survey indices of abundance. Currently too few fish are sampled as 1+ individuals in the trawl surveys for the Inshore Working Group to accept year class strengths derived from them. Ageing for this species is also uncertain, precluding the present separation of older size classes. Sufficient otoliths should continue to be collected to allow for proportions-at-age to be calculated – once a solution is found to the current ageing problems.
- The surveys appear to be monitoring both pre-recruit (1+) and recruited biomass with moderate *c.v.s*.

Tarakihi

- The existing survey boundaries may not appear to cover the full depth range for this species within the Bay of Plenty component of TAR 1. The timing of the survey may also miss a large component of the stock that may emigrate outside of the survey area for spawning.
- Only the 1996 and 1999 surveys had tarakihi specified as a target species, with 150–250 m strata added to improve the spatial coverage for this species. Despite this, highest biomass estimates were made in years before the deeper strata were added. This species may have year to year differences in its availability to the trawl year (with respect to depth), however the high c.v.s associated with the biomass estimates make comparisons of different surveys for biomass changes problematic.
- Biomass estimates are very modest compared to the commercial catch from this area, suggesting that the ability of the time series to monitor changes in stock abundance may be limited.
- The current survey design does not appear to be monitoring tarakihi stock abundance well, and may be flawed with respect to depth range, and possibly with change in spatial vulnerability of the stock between years.

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Table 1 : **Number of stations, total catch*, and mean catch rate (kg.km^{-2}) per tow*, 1986–99**

	KAH8303	KAH8506	KAH9004	KAH9202	KAH9601	KAH9902
Number of stations	63	87	63	89	80	78
10 - 150 m	63	87	63	89	67	58
150 - 250 m	-	-	-	-	13	20
Total catch (t)	N/A	N/A	11.8	11.5	8.7	4.8
Mean catch rate per tow (kg.km^2)			1 385	1 293	1 094	769

* Includes only comparable strata (10 - 150 m)

Table 2: **Estimated total biomass (t) and coefficient of variation (*c.v.* %) for the major commercial species.**

	KAH8303		KAH8506		KAH9004		KAH9202		KAH9601		KAH99902	
	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)
Jack mackerel												
Trachurus declivis	3	56	+	85	#		#				10	26
Including 150–200 m strata											95	53
T. novaezelandiae	504	33	306	89	19	61	#		1 132	56	359	34
Including 150–200 m strata									1 133	55	374	33
T. sp	86	67	109	35	53	59	117	28	3	96	—	—
John dory	113	24	111	12	157	16	236	12	192	44	172	14
Including 150–200 m strata									193	44	175	14
Leatherjacket	61	30	48	39	132	16	255	28	118	21	87	19
Red gurnard	348	22	48	16	413	11	271	10	320	14	362	14
Including 150–200 m strata											364	14
Rough skate	57	31	21	87	0				55	37	68	28
Including 150–200 m strata									55	37	70	27
Skate (unidentified)					15	94	64	43	—	—	—	—
Snapper	127	21	482	13	1 565	12	1 138	10	969	14	1 639	18
Including 150–200 m strata									970	14	1 646	18
Tarakihi	6	48	169	98	13	66	112	31	20	72	25	39
Including 150–200 m strata									35	46	51	27
Trevally	6	50	73	19	90	42	65	41	40	25	266	26
Including 150–200 m strata									40	25	266	26

+ less than 0.5 t

Species not separated

— Species properly identified

Table 3: **Estimated pre-recruit biomass (t) and coefficient of variation (c.v.) by year class (determined from length frequencies, size range given is across all surveys and varies slightly for individual surveys)**

	Size range (cm)	Age	KAH8303		KAH8506		KAH9004		KAH9202		KAH9601		KAH9902	
			Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)	Biomass	c.v. (%)
Jack mackerel														
Trachurus declivis	<10	0+	+	68										
	9–15	1+	1.1	68										
T. novaezelandiae	< 11	0+	57.6	37	+	54					+	99	9.7	67
	9–17	1+	369.0	42	35.8	93					821.5	75	129.6	31
	15–23	2+	51.8	68	223.9	89					125.2	73	170.8	57
John dory	19–34	1+	16.1	29	29.8	18	41.4	13	43.1	26	16.7	22	29.2	14
Leatherjacket	13–22	1+	5.3	30	1.7	36	1.8	21	127.2	47	0⊕		5.8	50
Red gurnard	<14	0+	+	37	+	88	+	19	0.0	77	0.0	60	+	50
	12–20	1+	5.8	25	+	56	8.8	39	+	26	1.1	34	2.1	33
Snapper	<15	1+	6.3	48	+	78	26.4	34	8.5	25	12.0	24	2.4	40
	14–23	2+	20.3	29	10.3	19	53.7	27	45.0	21	60.5	29	193.8	24
Trevally	15–25	1+	+	97	0.0	47	+	49	0.0		0.0	0	0.0	100
	16–27	2+	+	100	9.5	52	6.4	66	3.0	64	2.1	52	3.7	62

\+ Less than 0.5 t

⊕ Probably some juveniles caught but none measured

Table 4: **Percentage of female snapper (by 10 cm length class) at various gonad stages (1992–99). Only fish above 24 cm (50% length at maturity) were selected. For stage definitions refer to Appendix 5.**

	KAH9004							KAH9202						
	Gonad stage						*n*	Gonad stage						*n*
Length (cm)	1	2	3	4	5	6		1	2	3	4	5	6	
24–30	6	77	14	3	0	0	204	16	68	16	<0.5	0	0	766
31–40	0	87	12	1	0	0	160	2	61	36	1	0	0	231
41–50	0	94	6	0	0	0	32	0	58	42	0	0	0	12
51–60	0	100	0	0	0	0	3	0	33	67	0	0	0	3
>60	0	100	0	0	0	0	2	0	0	0	0	0	0	0
							401							1012

	KAH9601							KAH9902						
	Gonad stage							Gonad stage						
Length (cm)	1	2	3	4	5	6	*n*	1	2	3	4	5	6	*n*
24–30	<0.5	76.2	23.1	<0.5	0	0	286	5	79	13	1	<0.5	0	394
31–40	0	80.7	19.3	0	0	0	218	0	67	25	3	4	0	157
41–50	0	88.2	11.8	0	0	0	17	0	48	26	4	4	0	23
51–60	0	0	100	0	0	0	1	0	33	0	0	0	0	3
>60	0	0	50	0	50	0	2	0	0	0	0	0	0	0
							524							577

Table 5: **Percentage of John Dory, red gurnard, and tarakihi at various gonad stages from KAH9902. Only fish above a known maturity size were selected (John dory males > 35 cm, females > 38 cm; red gurnard > 25 cm; tarakihi> 33 cm). For stage definitions refer to Appendices 3, 4 and 6.**

John dory	Males						Females								
	Gonad stage					*n*	Gonad stage								*n*
	1	2	3	4	5		1	2	3	4	5	6	7	8	
	0	50.6	31	17.2	1.15	87	0	1	11	31	31	14	13	0	72

Red gurnard	Gonad stage					*n*	Gonad stage						*n*
Length (cm)	1	2	3	4	5		1	2	3	4	5	6	
25–30	7	67	13	1	13	220	18	36	14	4	0	28	214
31–40	0	34	19	5	42	113	0	17	40	13	3	26	268
>40	0	0	0	0	100	1	0	0	43	25	5	28	40
						334							522

Tarakihi	Gonad stage							*n*	Gonad stage							*n*
Length (cm)	1	2	3	4	5	6	7		1	2	3	4	5	6	7	
33–40	19	55	16	2	0	0	8	62	13	71	13	3	0	0	0	31
>40	0	33	33	0	0	0	33	3	0	50	50	0	0	0	0	4
								65								35

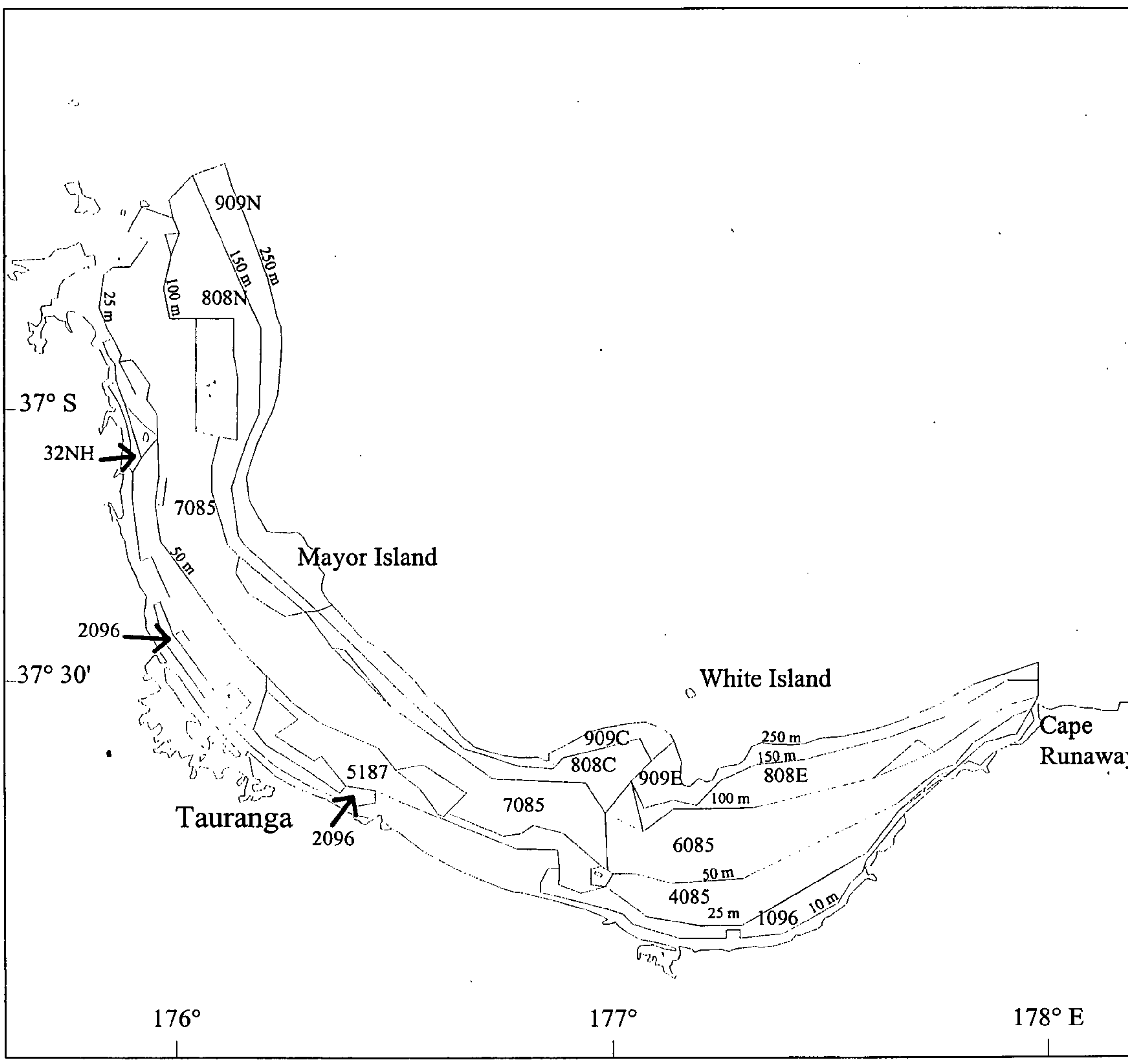

***Figure 1*: Stratum boundaries and numbers from the 1996 Bay of Plenty trawl survey (KAH9601) (foul ground not shown).**

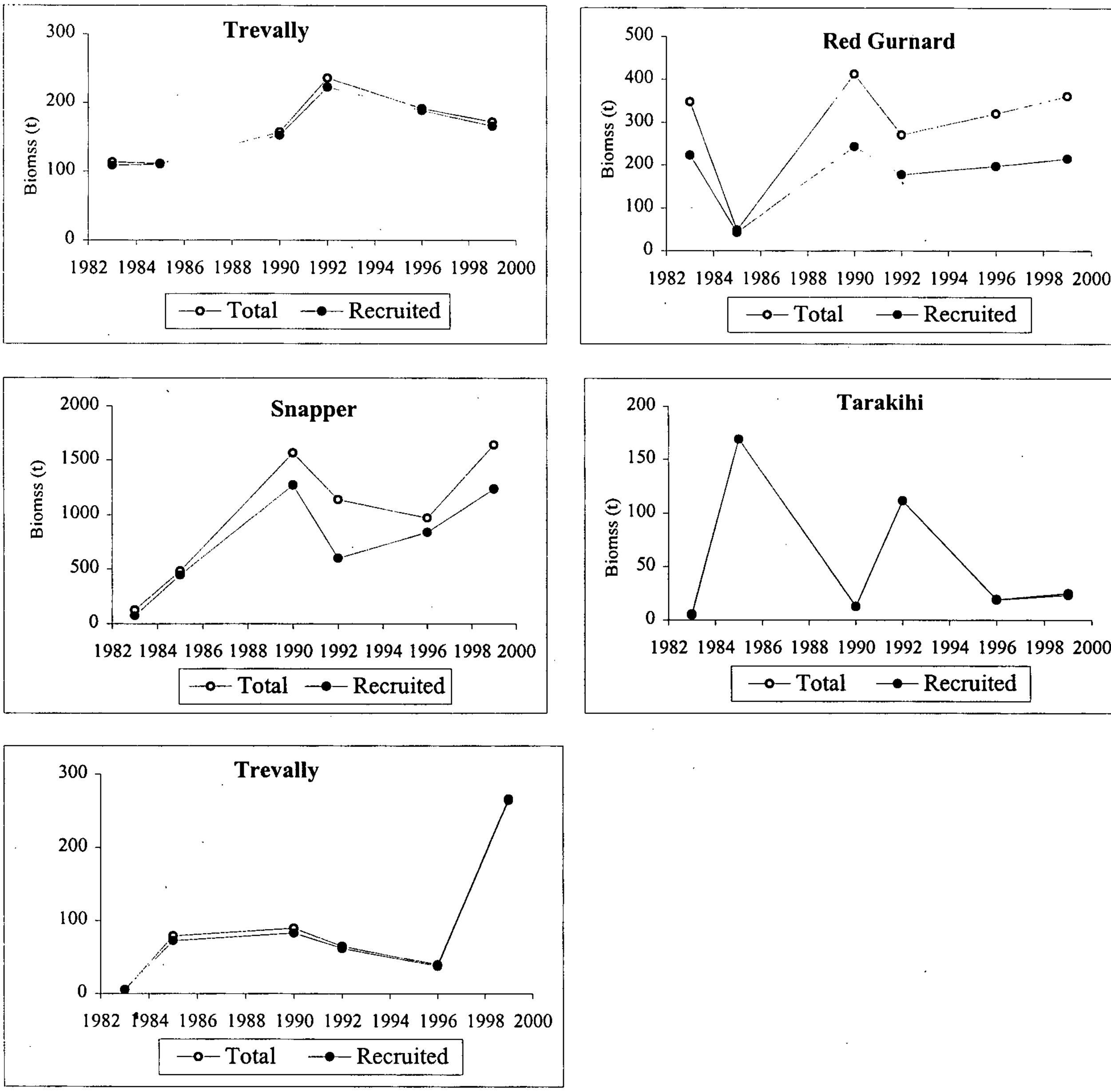

Figure 2: **Total and recruited biomass of John dory, red gurnard, snapper, tarakihi, and trevally,**

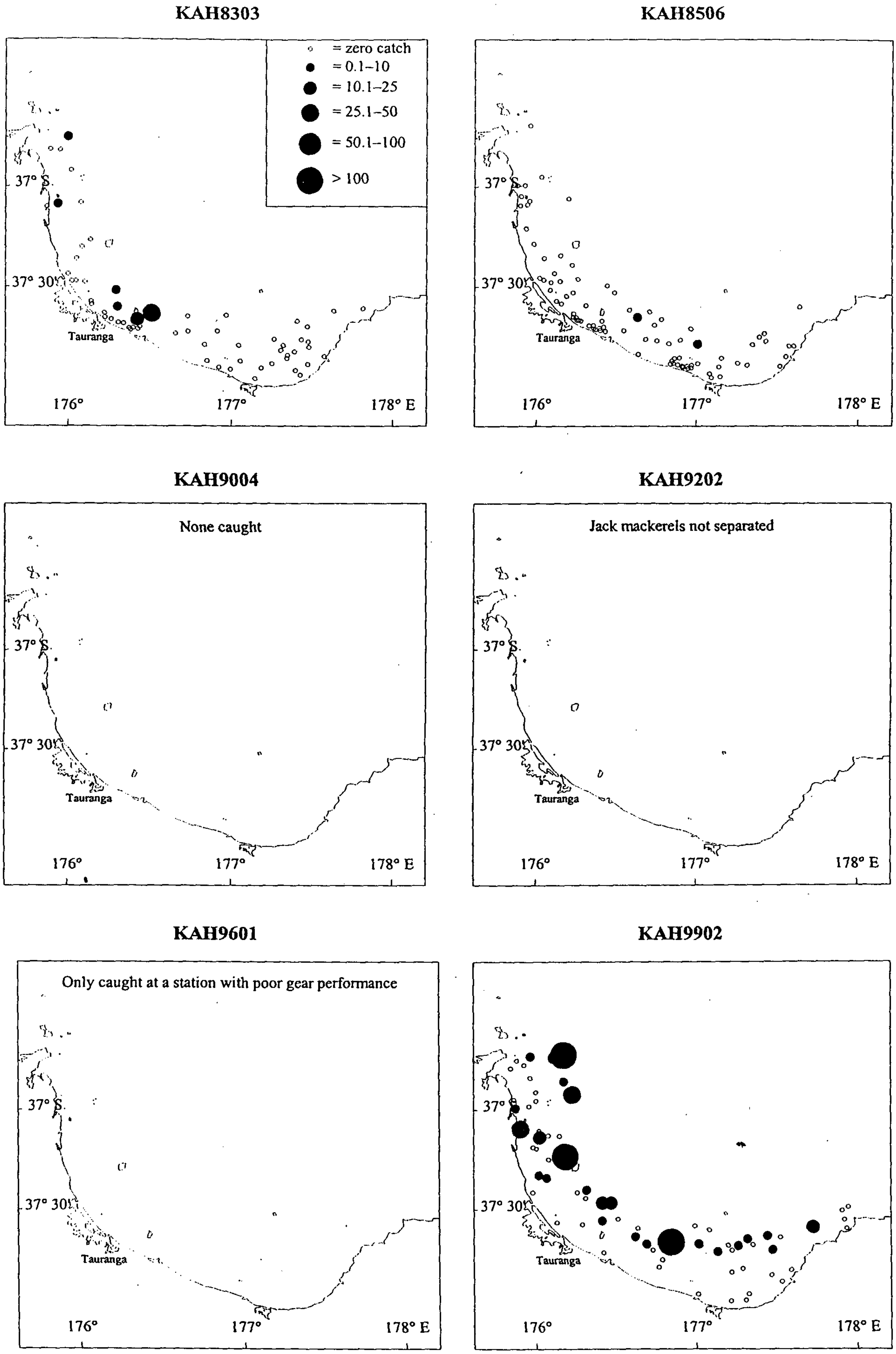

Figure 3 **: Distribution and catch rates (kg.km^{-2}) of the major species, 1983–99**
a**: Jack mackerel (*****Trachurus declivis*****) (maximum catch rate, 911 kg.km^{-2}).**

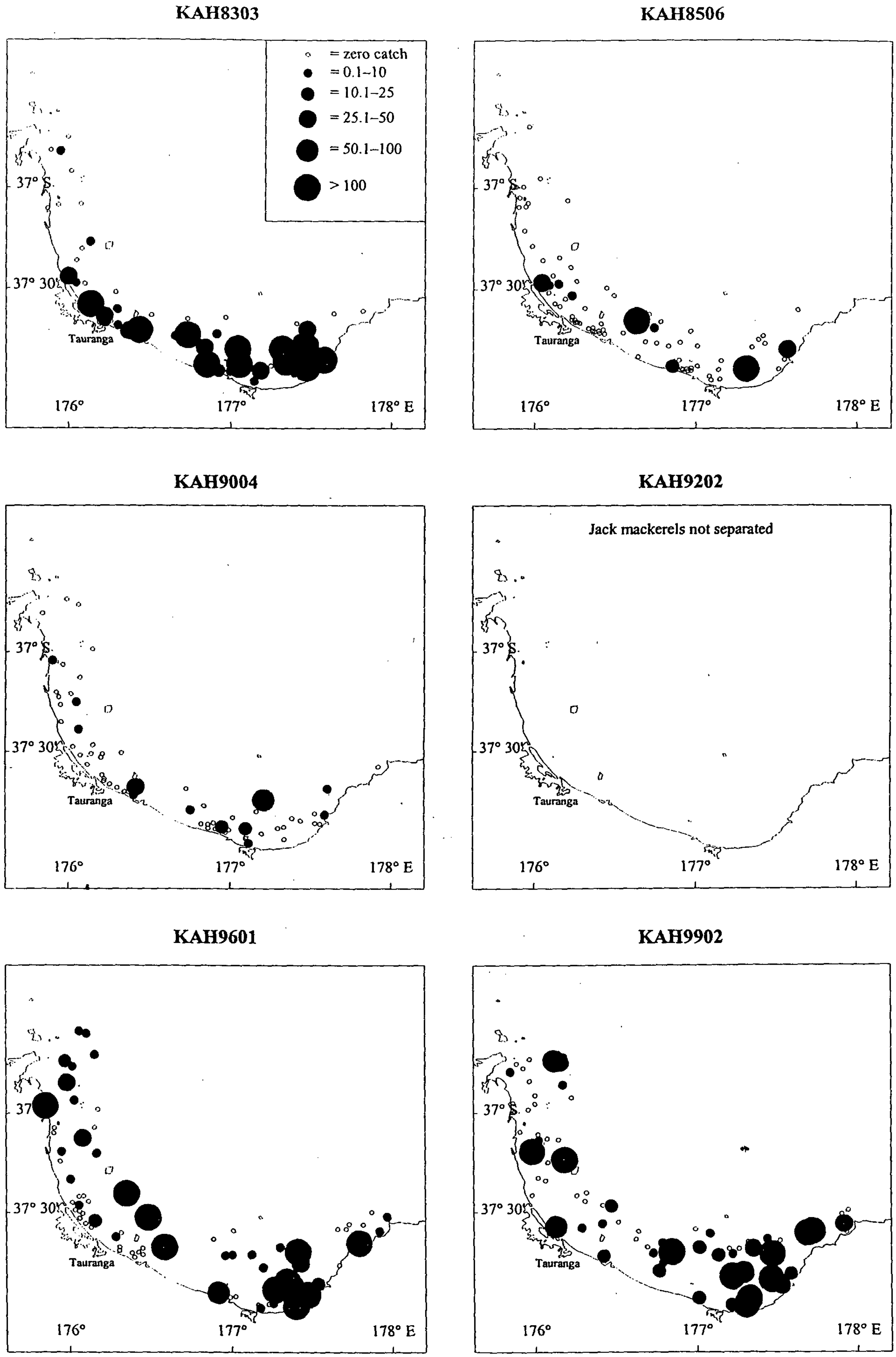

Figure 3b: **Jack mackerel (*Trachurus novaezelandiae*) (maximum catch rate, 2 060 kg.km -).**

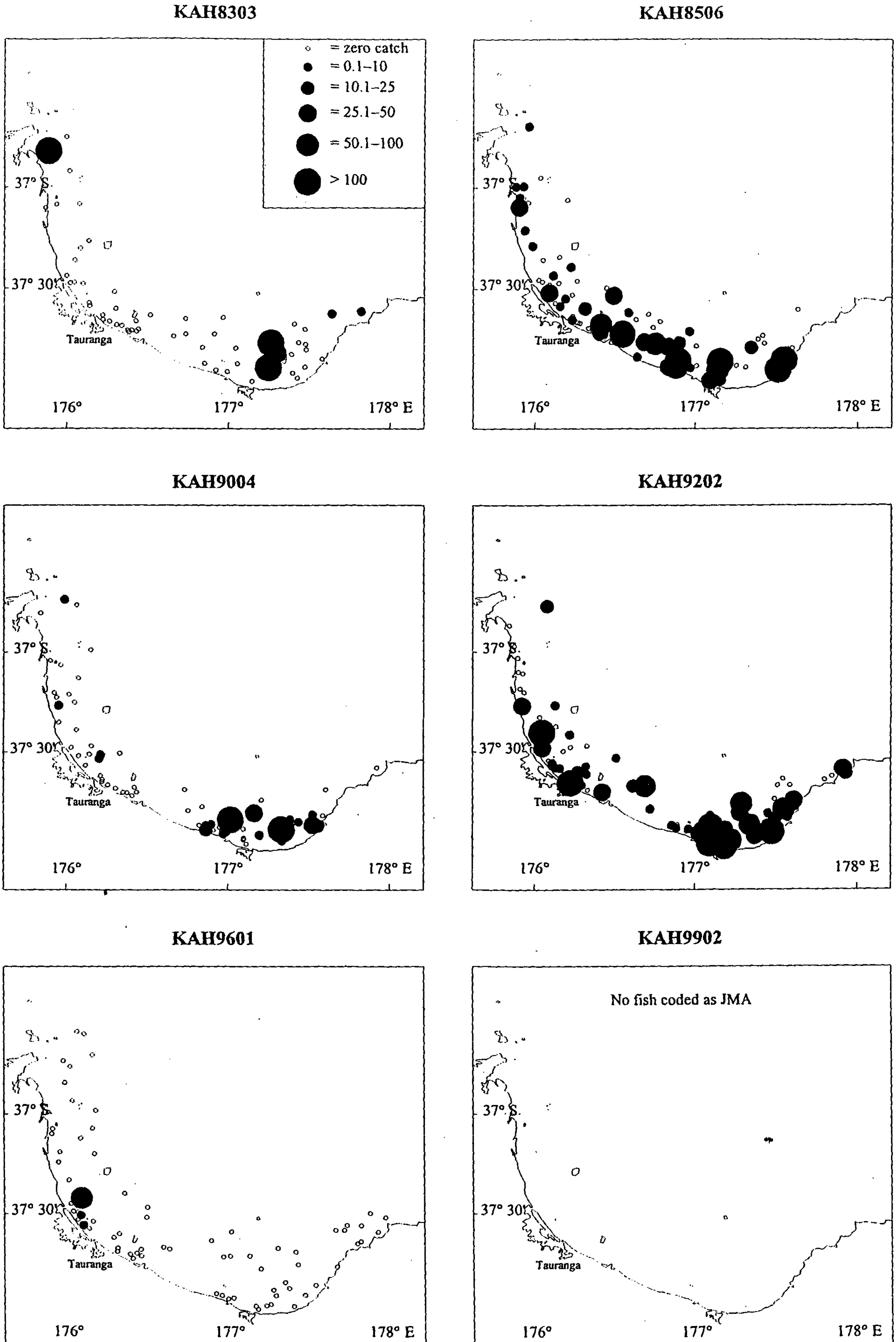

***Figure 3c*: Jack mackerel (*Trachurus* spp.) (maximum catch rate, 1 080 kg.km $^{-2}$).**

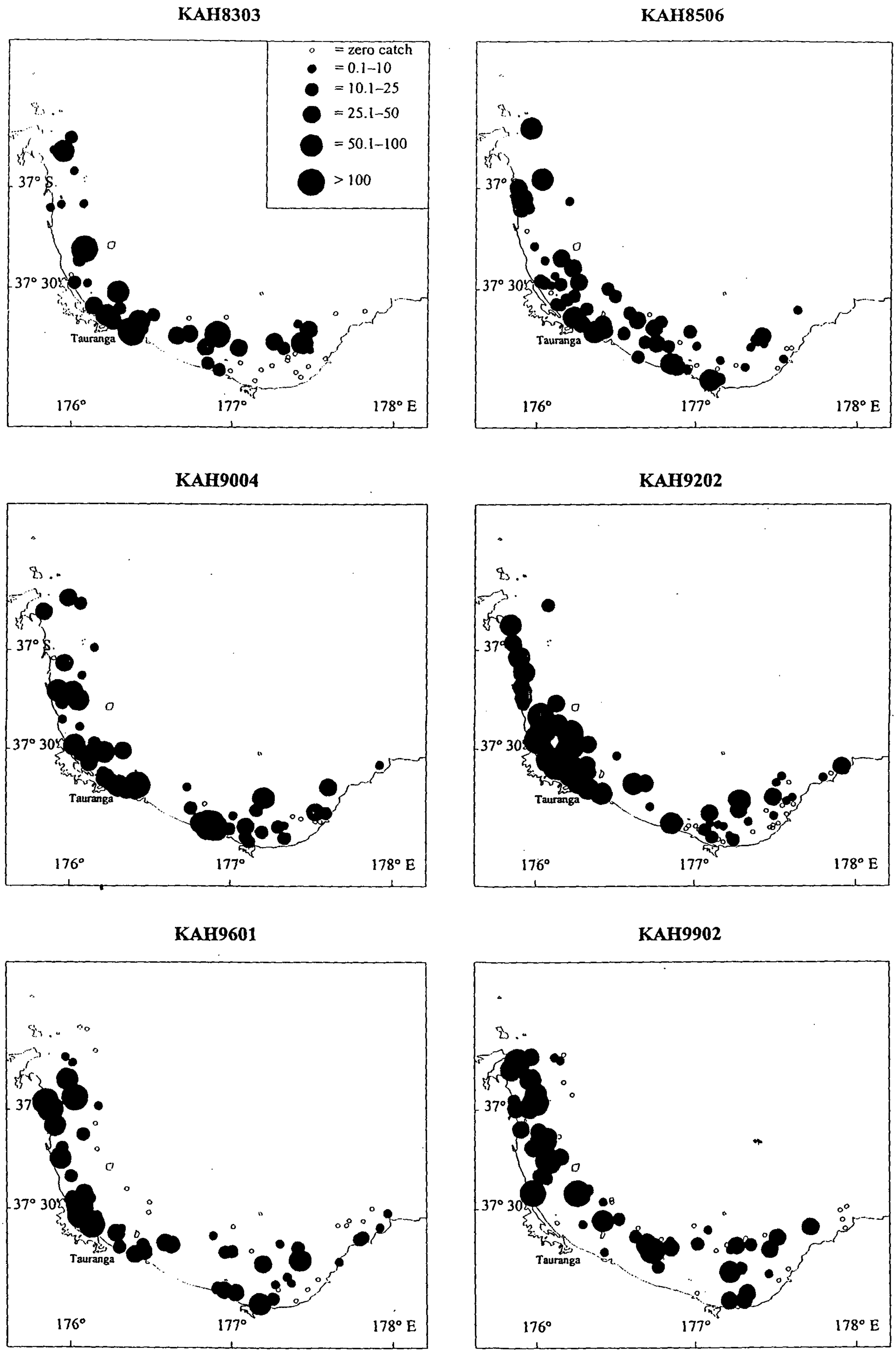

Figure 3d: **John dory (maximum catch rate, 228 kg.km⁻²).**

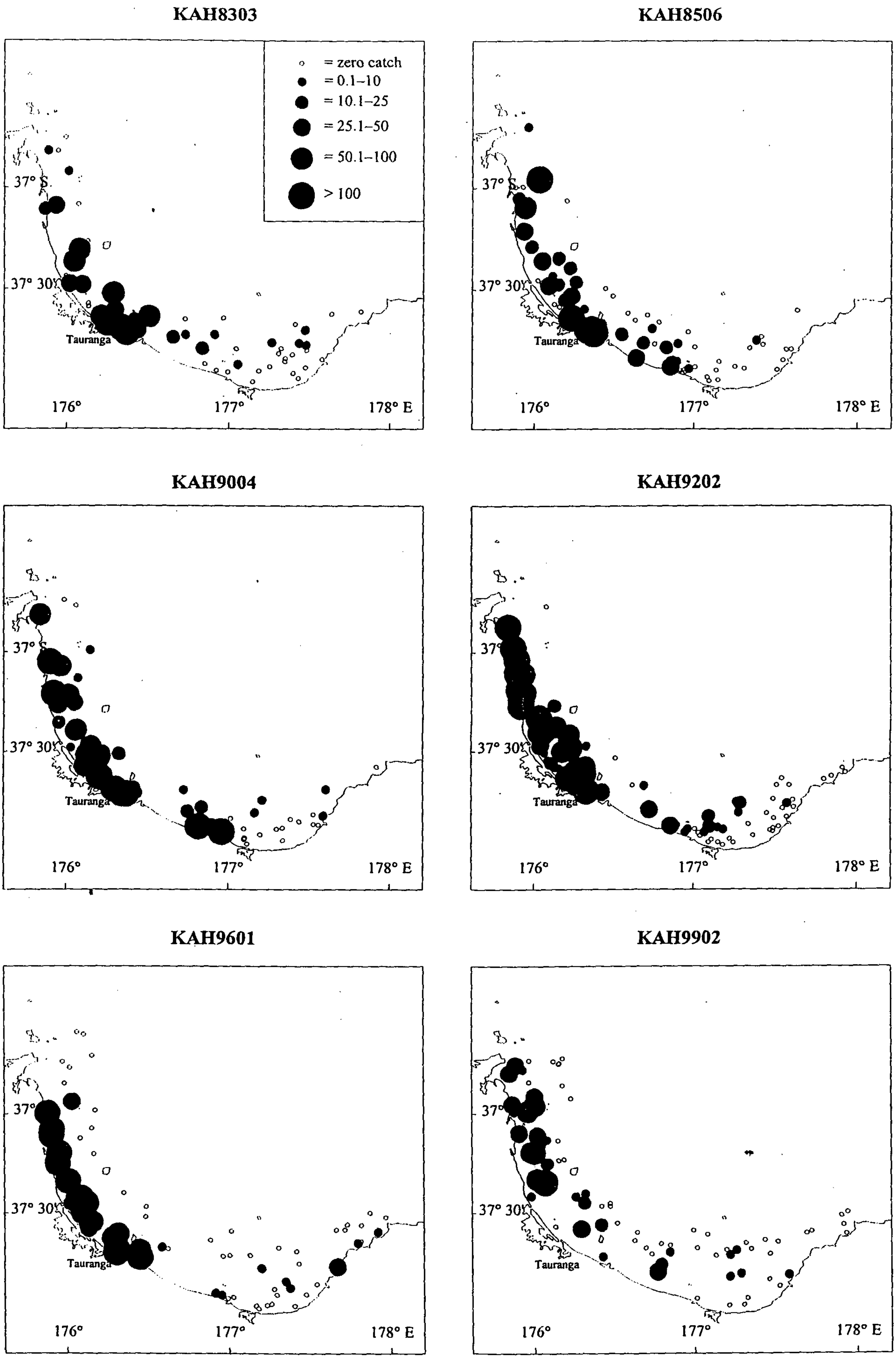

Figure 3e: **Leatherjacket (maximum catch rate, 1 460 kg.km⁻²).**

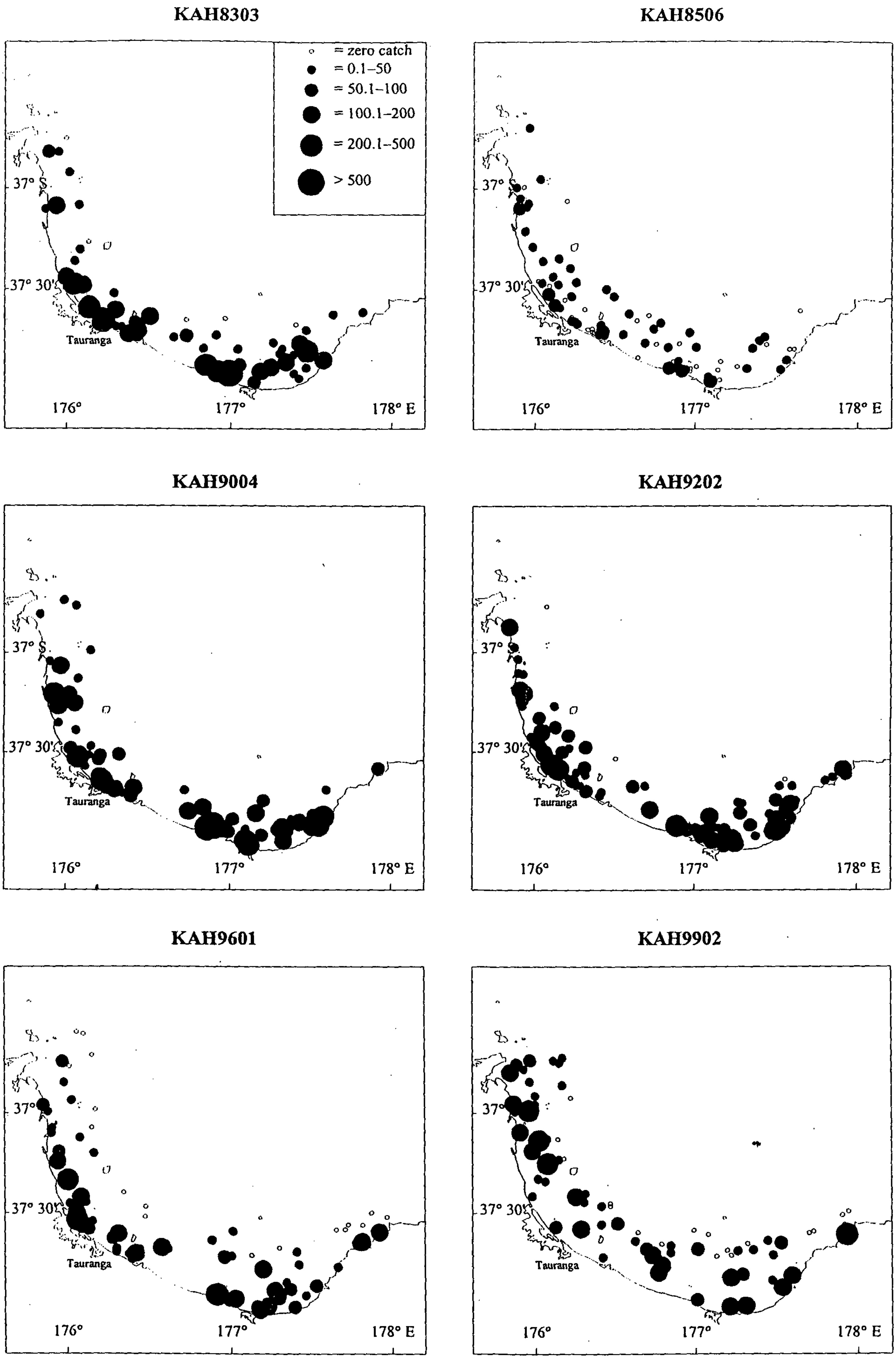

Figure 3f: **Red gurnard (maximum catch rate, 2 160 kg.km⁻²).**

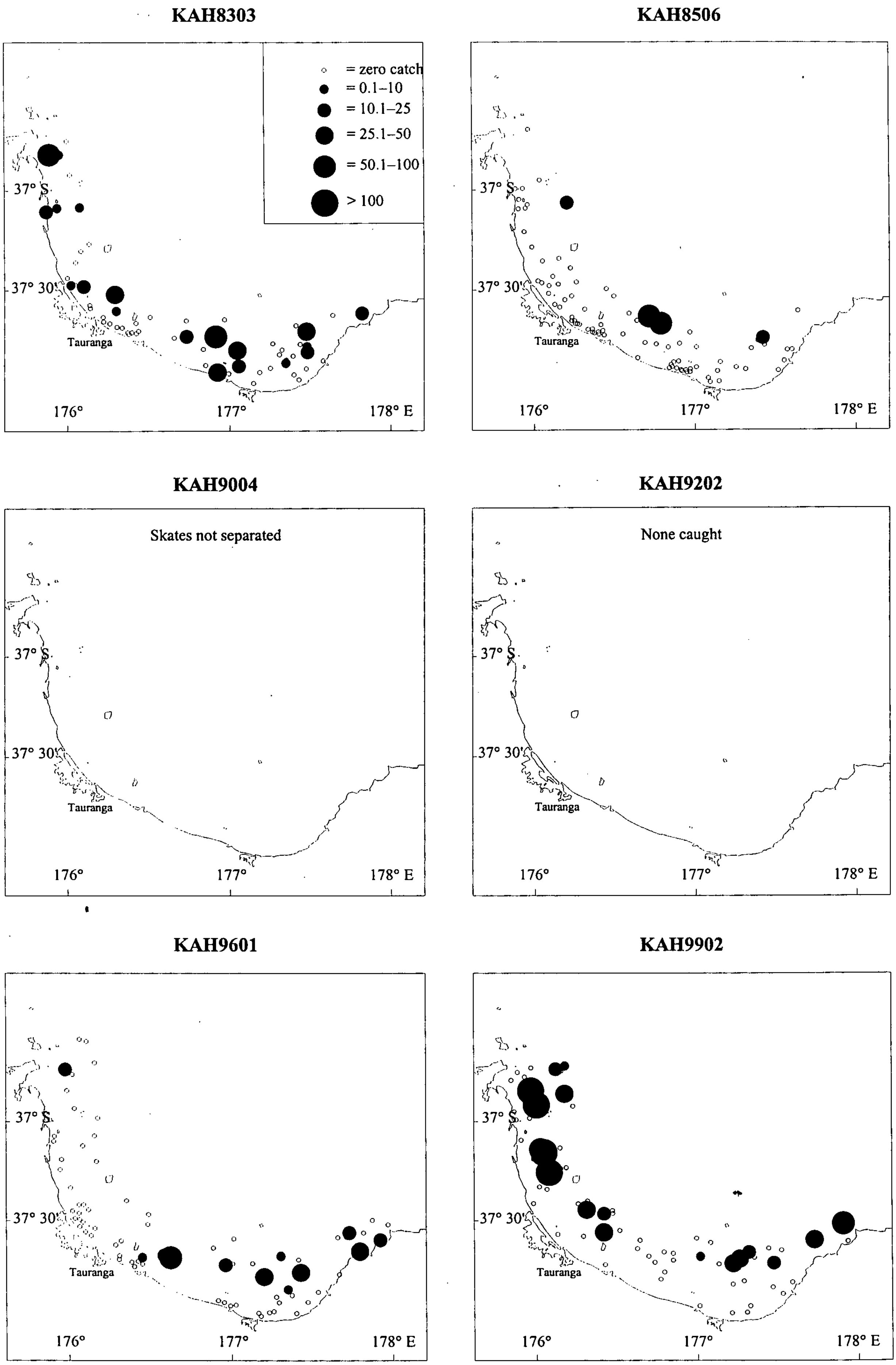

***Figure 3g*: Rough skate (maximum catch rate, 172 kg.km^{-2}).**

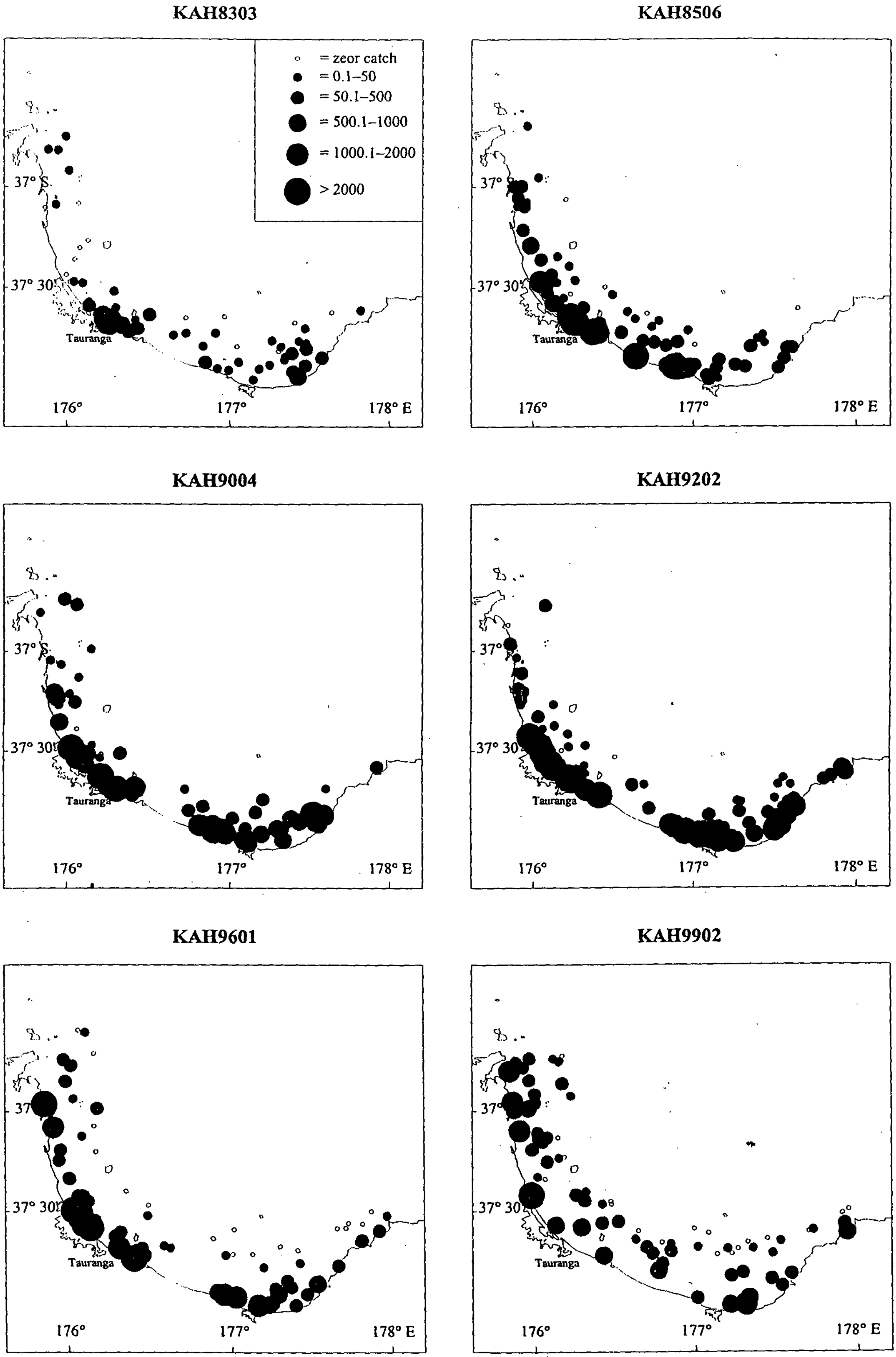

Figure 3h: **Snapper (maximum catch rate, 11 964 kg.km^{-2}).**

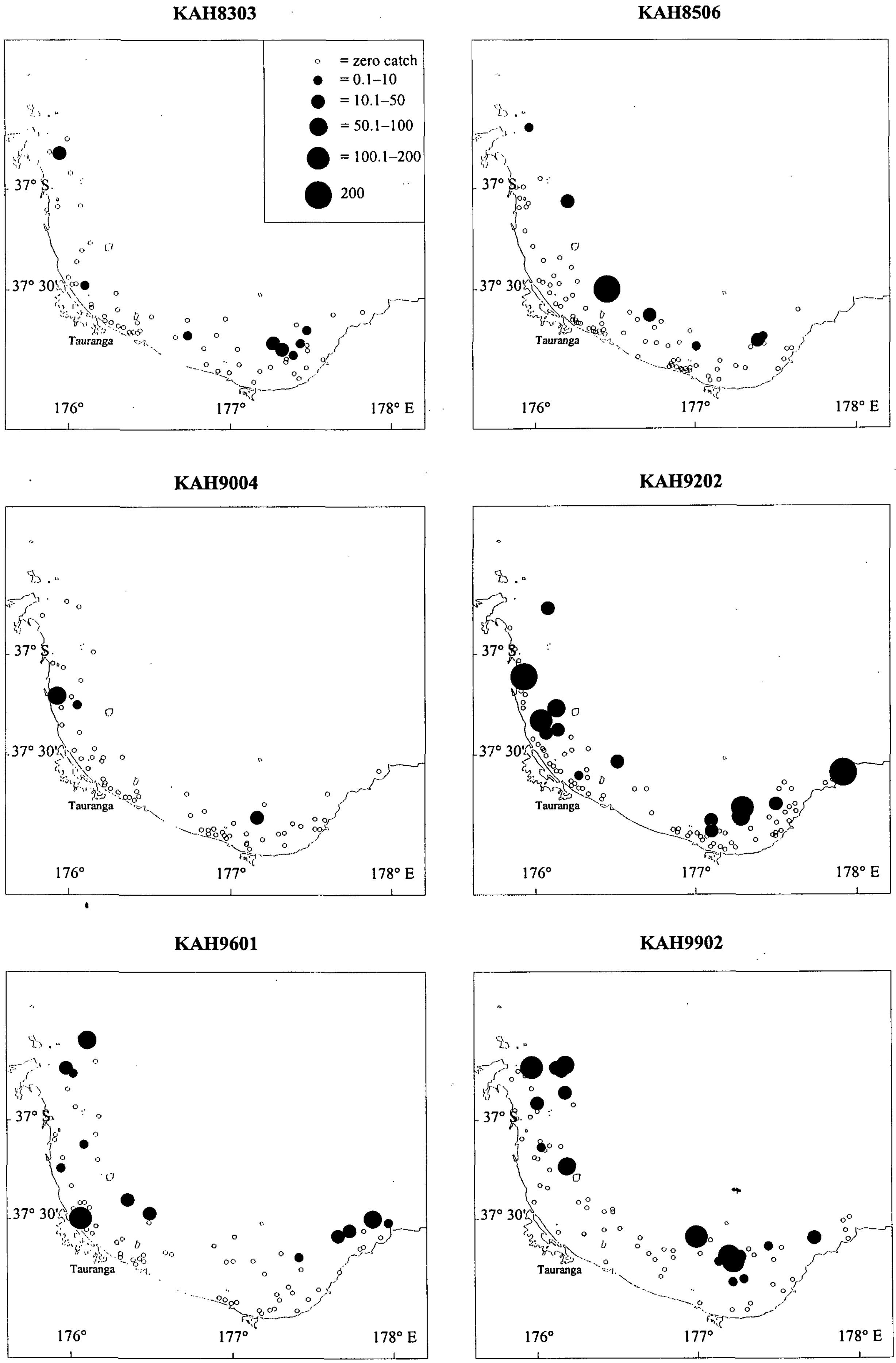

Figure 3i **: Tarakihi (maximum catch rate, 603 kg.km^{-2}).**

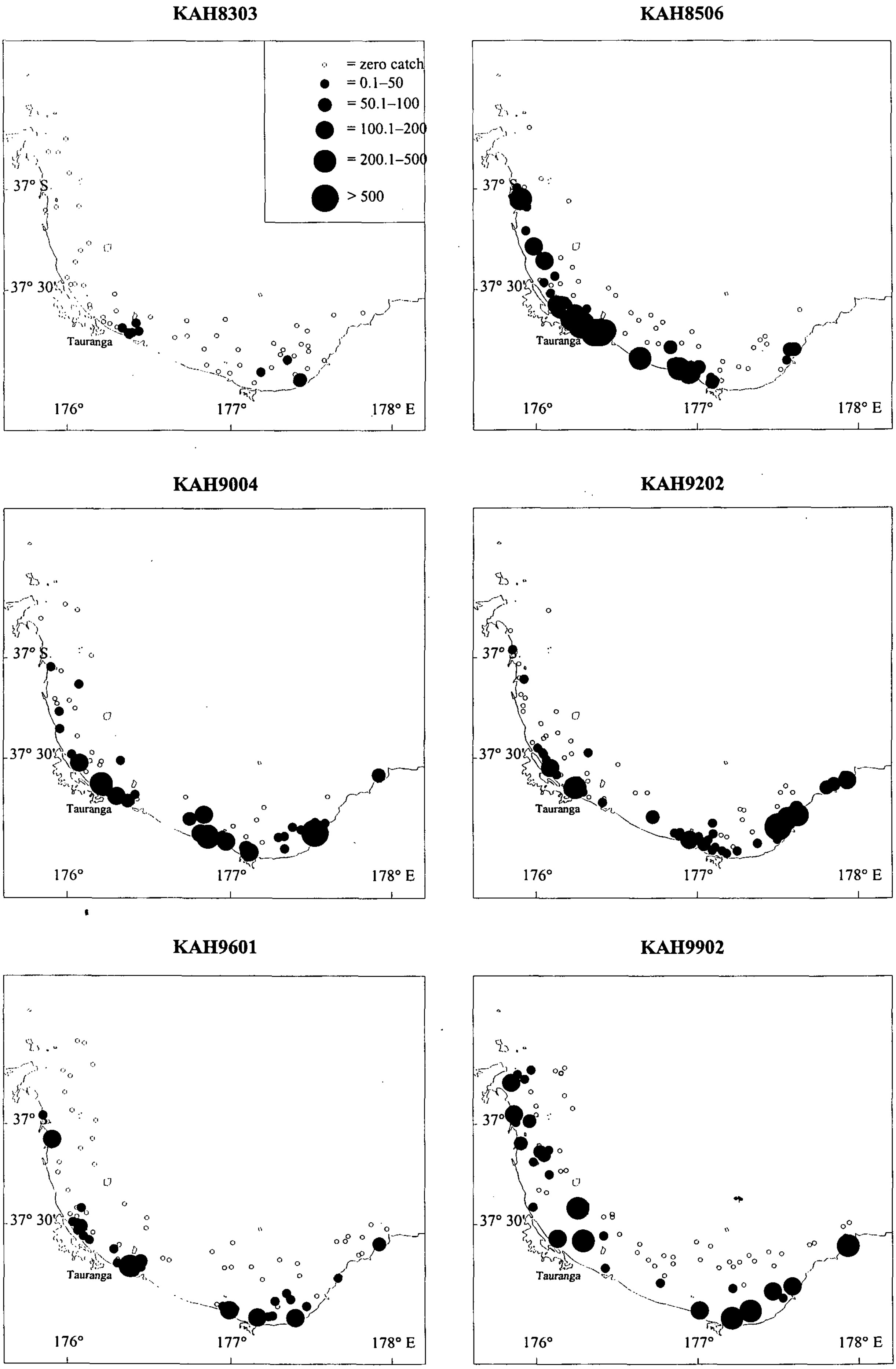

Figure 3j : **Trevally (maximum catch rate, 1 243 kg.km^{-2}).**

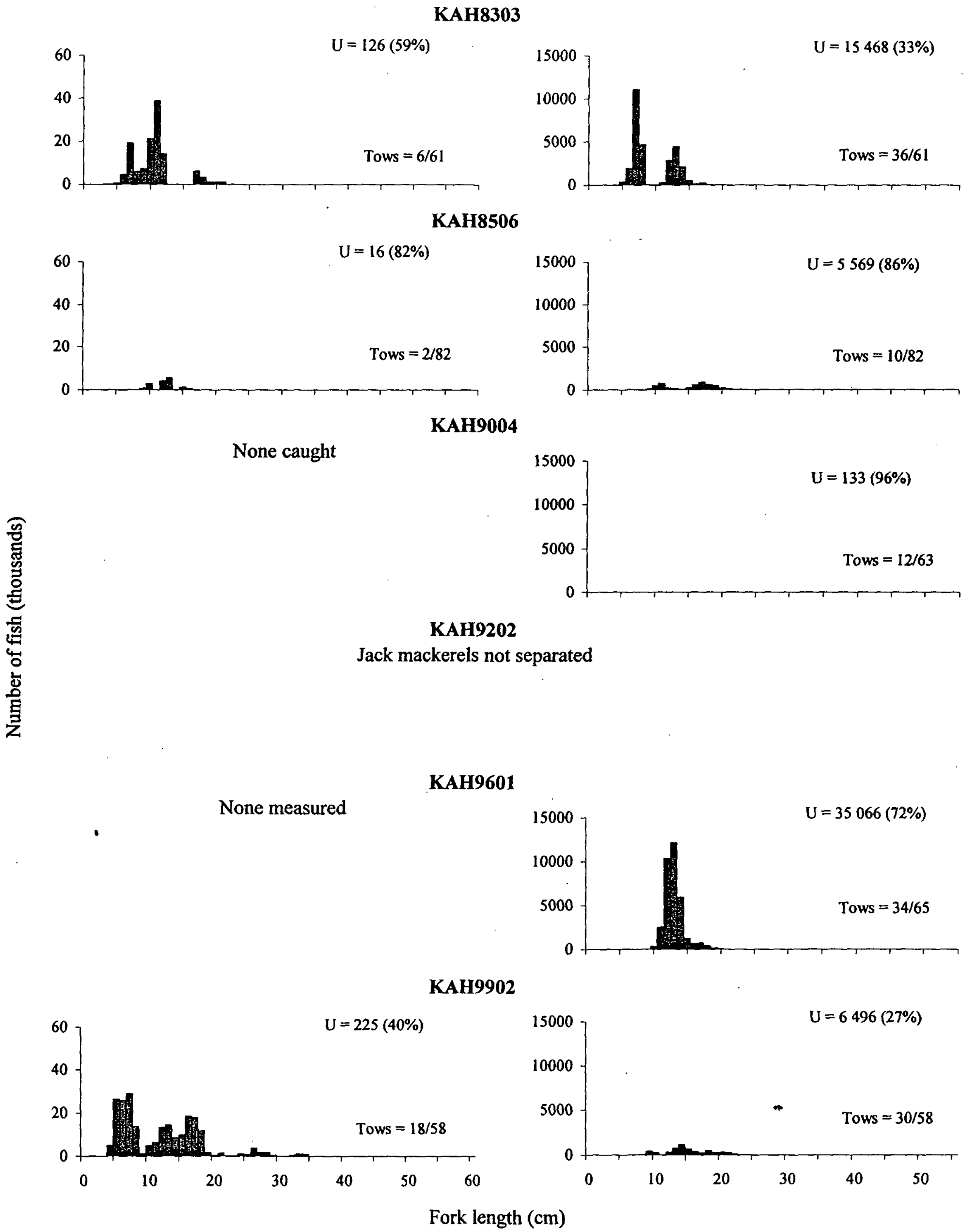

***Figure 4*: Scaled length frequency distributions of the major species, 1983–99, with the estimated total number of fish in the population (thousands) (and percentage coefficient of variation). M, number of males; F, number of females; U, number of unsexed fish; Tows, number of stations at which the species was caught/total number of stations.**

***a*: Jack mackerel (left, *Trachurus declivis*; right, *T. novaezelandiae*).**

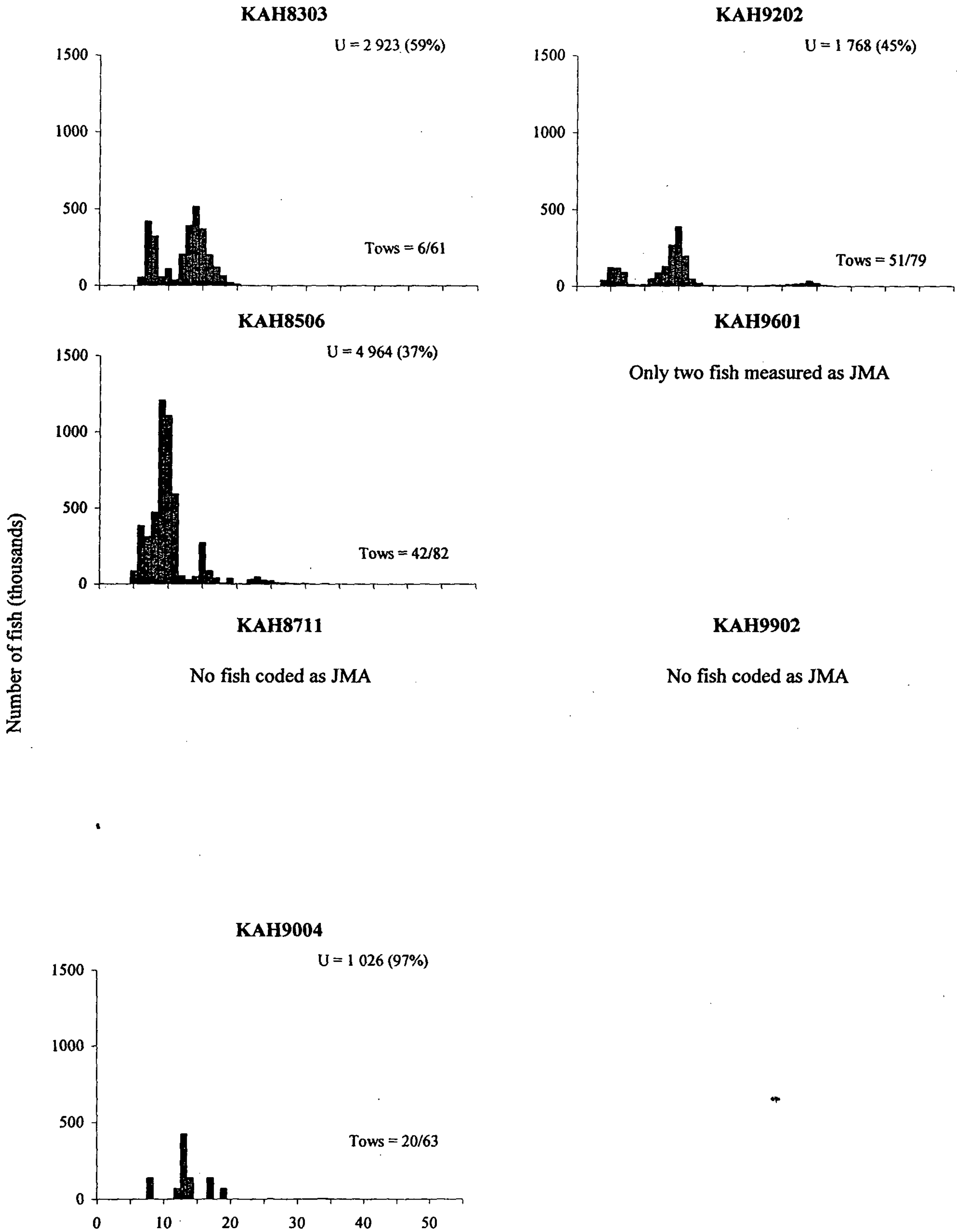

Figure 4b **: Jack mackerel (*Trachurus* spp.).**

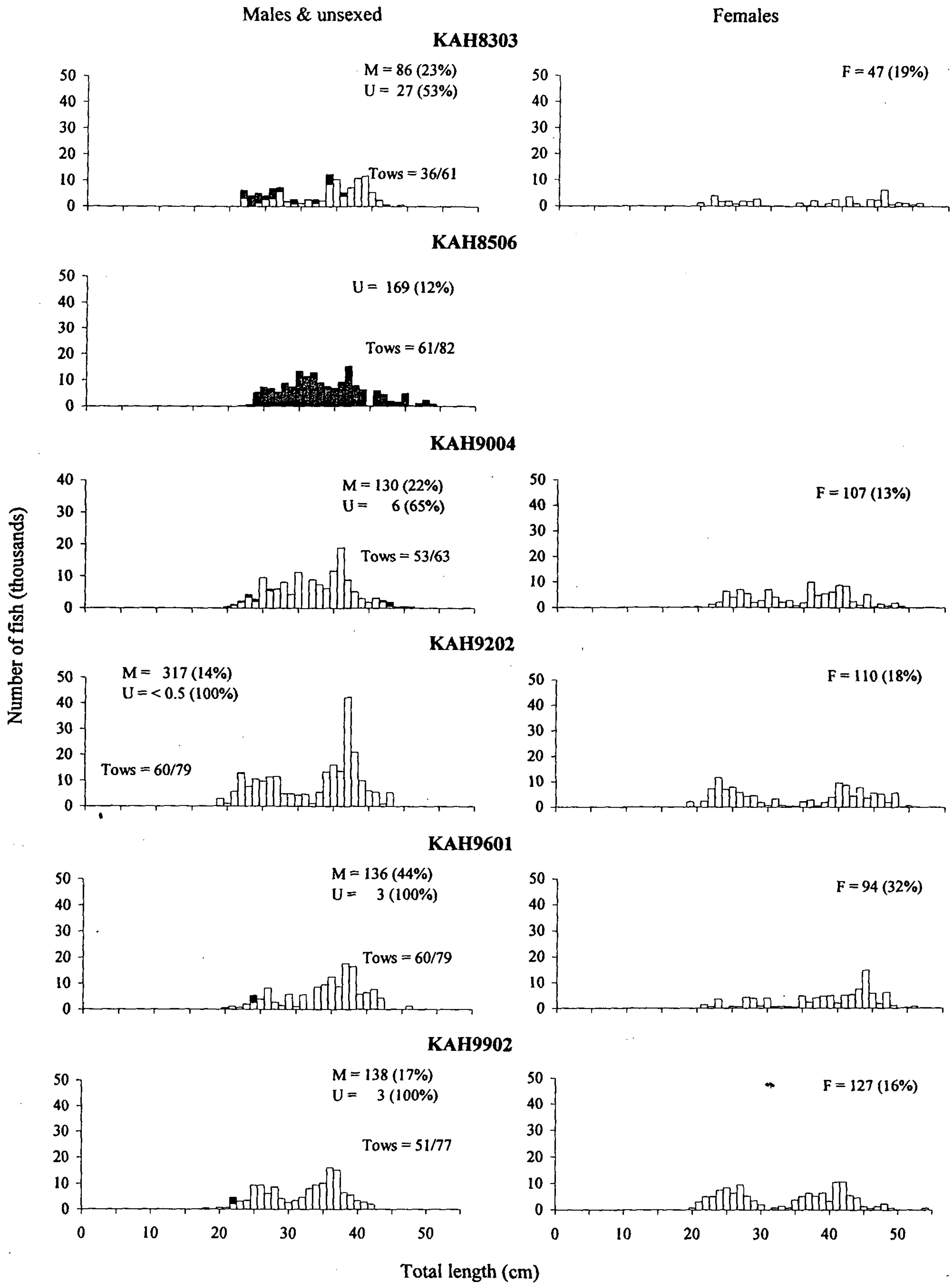

Figure 4c: **John dory.**

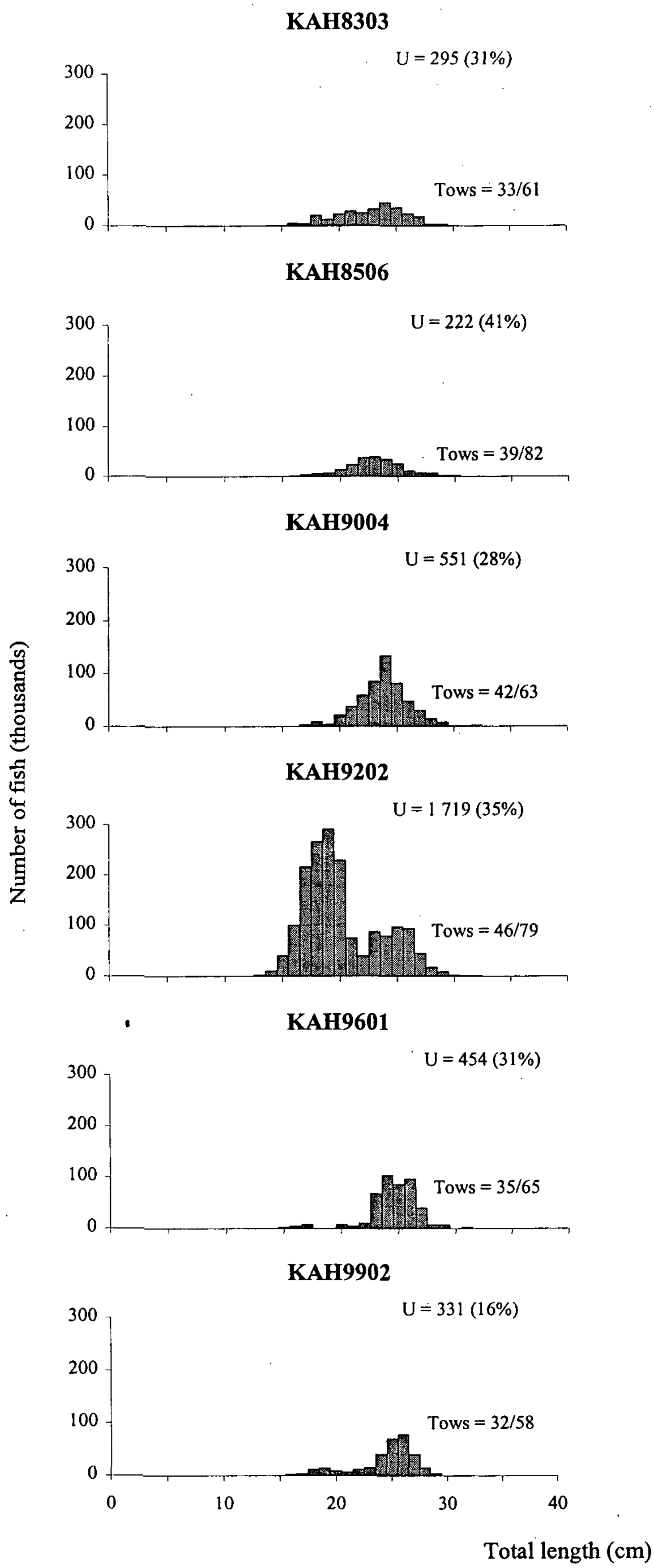

***Figure 4d*: Leatherjacket.**

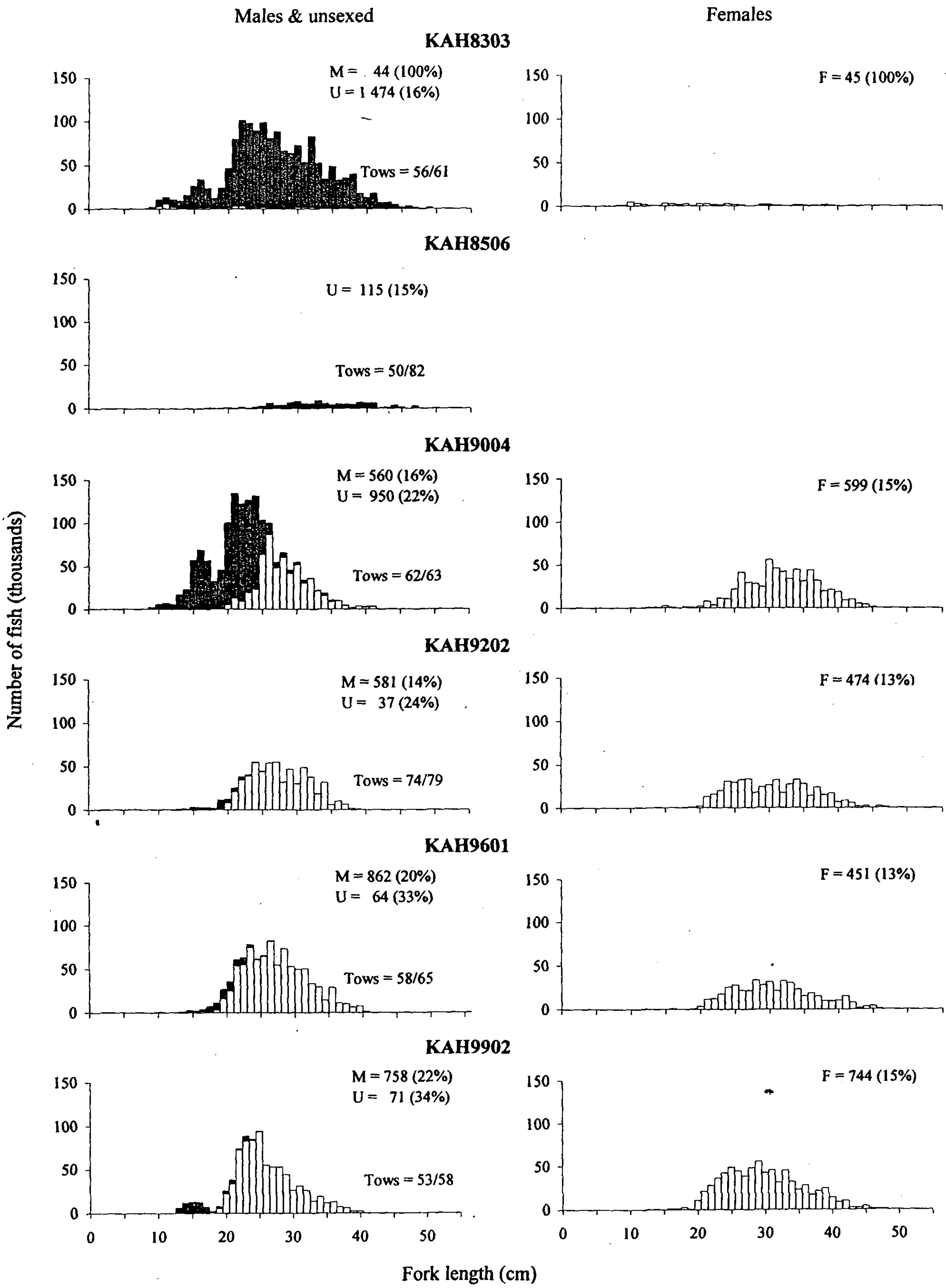

Figure 4e **: Red gurnard.**

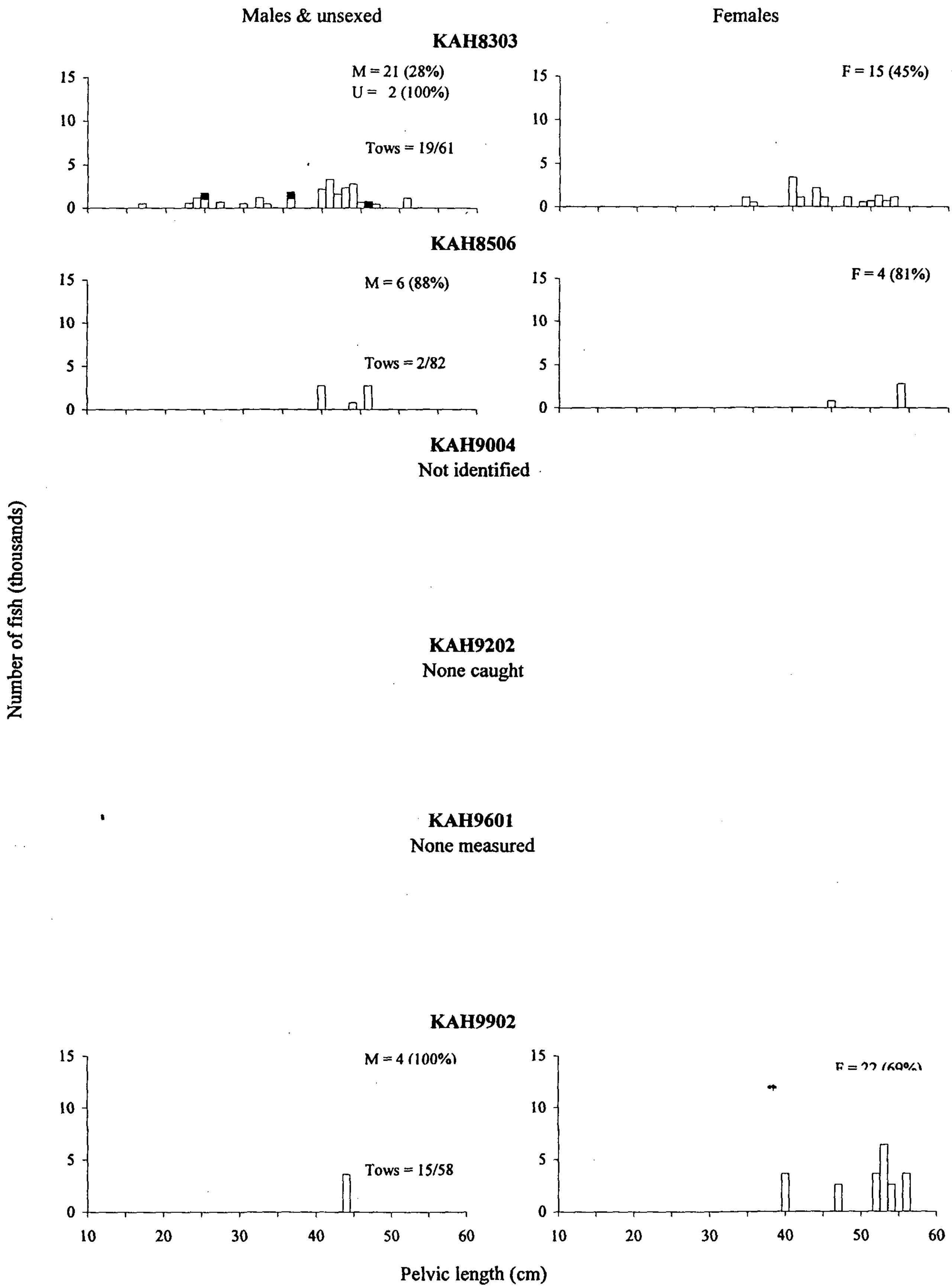

***Figure 4f*: Rough skate.**

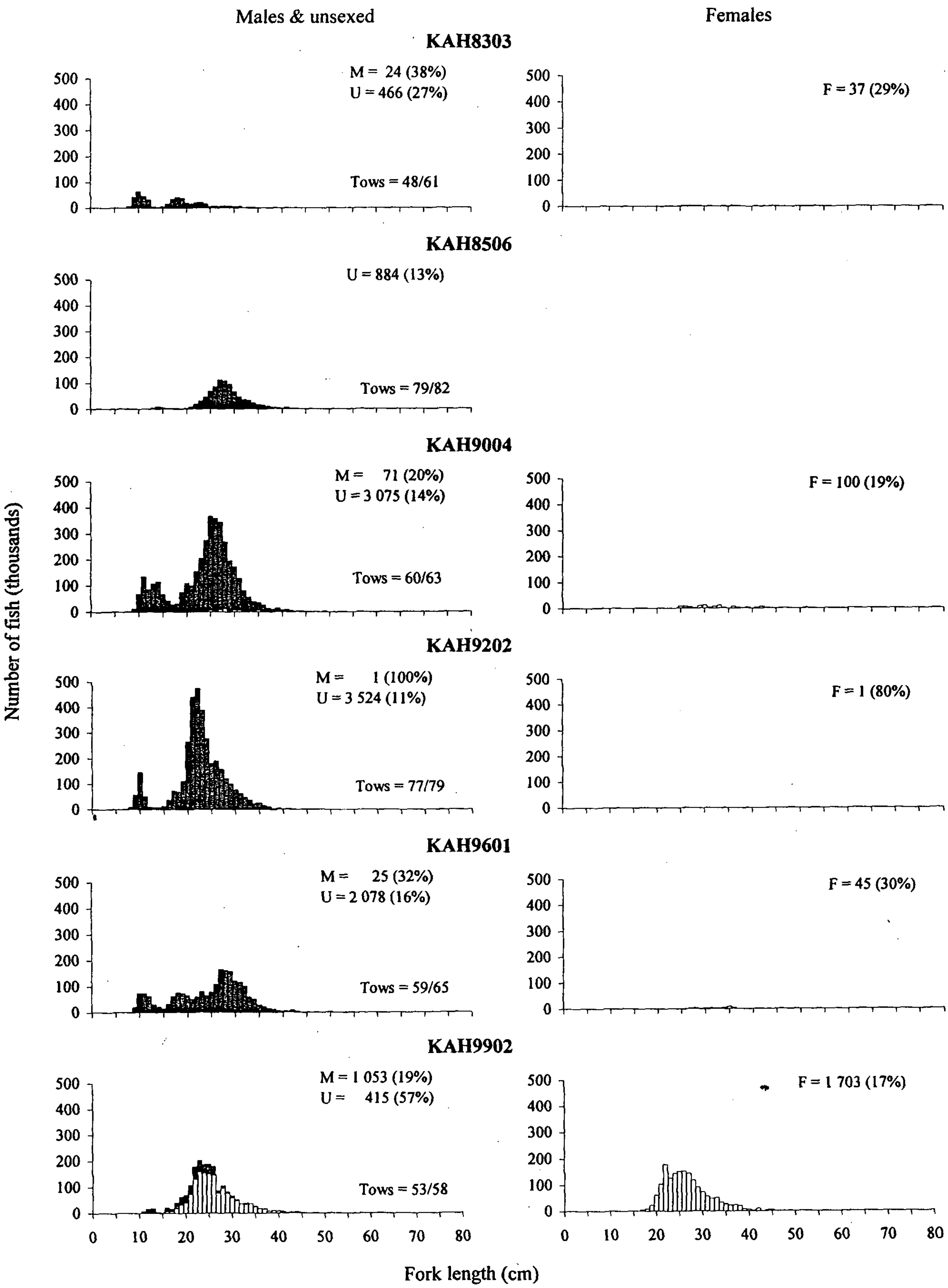

Figure 4g **: Snapper.**

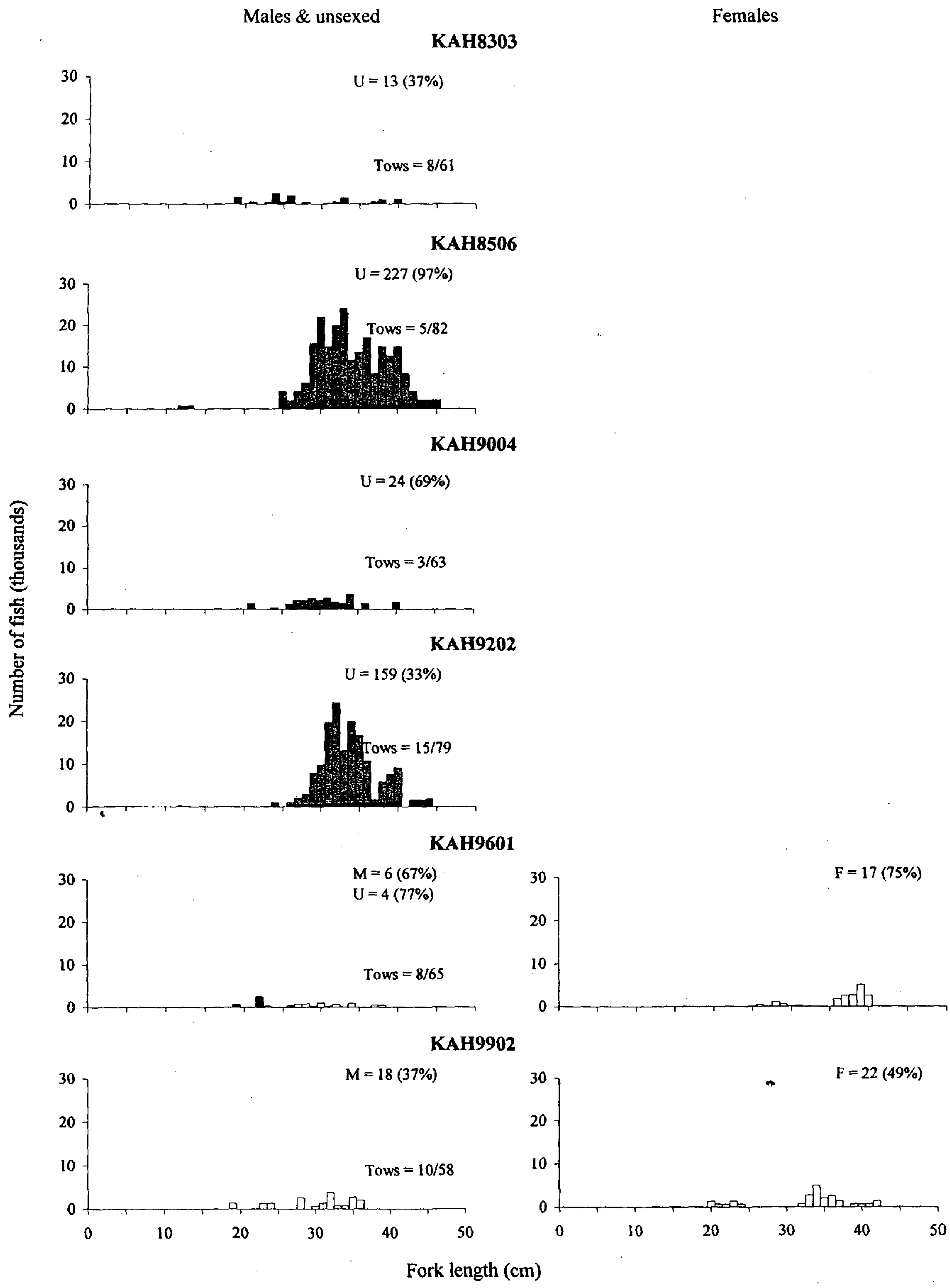

Figure 4h **: Tarakihi.**

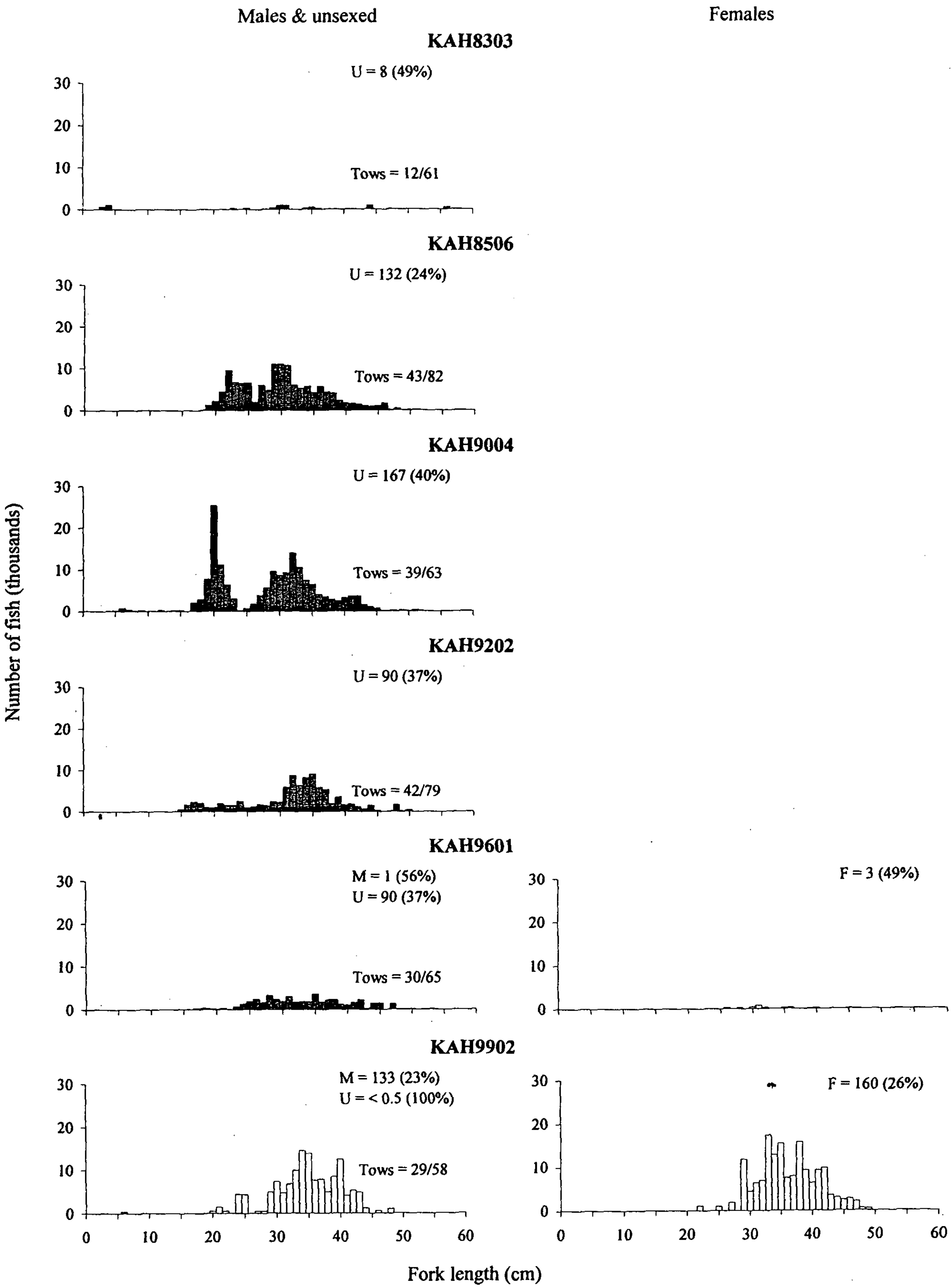

Figure 4i: **Trevally.**

Appendix 1: Gear parameters by depth range. Doorspread values for KAH8303 through KAH9202 set by the equation $Doorspread = 88.8214 * (1-e^{-0.0096994(warplength + 7.3296)})$; **–, No data.**

	KAH8303				KAH8506				KAH9004				KAH9202			
	n	Mean	s.d.	Range	*n*	Mean	s.d.	Range	*n*	Mean	s.d.	Range	*n*	Mean	s.d.	Range
Gear parameters (m)																
10–25 m																
Headline height	–	–	–	–	–	–	–	–	26	4.7	0.3	4.0–5.0	33	6.42	0.2	6.0–7.0
Doorspread	21	59.8	4.8	57.5–69.5	42	44.2	4.8	32.7–57.5	26	75.8	1.8	71.3–76.9	33	73.2	4.6	63.0–81.5
Warp/depth ratio	21	5.3	1.0	4.00–7.14	42	3.8	0.6	2.73–5.52	26	9.4	1.6	7.20–14.29	33	9.1	1.5	6.67–12.82
25–50 m																
Headline height	–	–	–	–	–	–	–	–	23	4.67	0.2	4.5–5.0	28	6.2	0.4	5.0–7.0
Doorspread	19	70.9	64.5	57.5–76.9	20	65.7	3.5	57.5–71.3	23	76.9	0.0	76.9–76.9	28	79.6	2.9	72.9–84.3
Warp/depth ratio	13	4.0	0.7	2.27–5.00	20	3.5	0.4	2.82–4.56	23	5.4	1.1	4.0–7.69	28	6.4	1.0	5.06–7.94
50–100 m																
Headline height	–	–	–	–	–	–	–	–	10	4.7	0.2	4.5–5.0	13	6.15	0.2	6.0–6.5
Doorspread	19	81.7	2.9	76.9–86.0	17	80.4	4.7	72.9–86.0	10	80.9	3.1	76.9–84.3	13	84.7	1.3	81.5–86.0
Warp/depth ratio	19	3.5	0.3	3.18–4.03	17	3.4	0.3	3.00–3.91	10	3.5	0.3	2.94–3.85	13	4.4	0.7	3.68–5.83
100–150 m																
Headline height	–	–	–	–	–	–	–	–	4	4.9	0.3	4.5–5.0	5	6.2	0.3	6.0–6.5
Doorspread	6	86.8	1.3	84.3–87.8	3	85.4	0.9	84.3–86.0	4	86.8	1.7	84.3–87.8	5	86.7	0.6	86–87.1
Warp/depth ratio	6	3.2	0.3	2.65–3.59	3	3.2	0.2	2.86–3.33	4	3.5	0.4	2.94–3.88	5	3.1	0.1	3.02–3.28
150–250 m																
Headline height	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Doorspread	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Warp/depth ratio	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10–150 m																
Headline height	–	–	–	–	–	–	–	–	63	4.7	0.3	4.0–5.0	79	6.28	0.3	5.0–7.0
Doorspread	61	72.0	11.1	57.5–87.8	82	58.4	16.3	32.7–86.0	63	77.7	3.4	71.3–87.8	79	78.2	5.9	63.0–87.1
Warp/depth ratio	61	4.2	1.1	2.27–7.14	82	3.6	0.5	2.73–5.52	63	6.6	2.7	2.94–14.29	79	7.0	2.3	3.02–12.82

Appendix 1—*continued*

Gear parameters (m)	KAH9601				KAH9902			
	n	Mean	s.d.	Range	*n*	Mean	s.d.	Range
10–25 m								
Headline height	26	5.7	0.2	5.5–6.4	11	6.3	0.2	6.0–6.6
Doorspread	26	81.2	2.6	77–88.1	11	80.2	2.5	75.4–85.0
Warp/depth ratio	26	10.3	2.4	8.00–17.39	11	9.5	1.8	8.00–13.79
25–50 m								
Headline height	19	5.7	0.2	5.3–6.0	6	6.1	0.1	5.9–6.2
Doorspread	19	82.2	2.3	79.3–87.2	6	81.9	1.9	79.6–84.4
Warp/depth ratio	19	5.6	1.2	4.08–7.69	6	5.2	1.1	4.21–6.67
50–100 m								
Headline height	8	5.6	0.3	5.1–6.2	29	6.2	0.3	5.9–7.6
Doorspread	8	87.0	5.5	80.0–93.2	29	84.0	3.4	73.3–89.1
Warp/depth ratio	8	3.4	0.2	3.13–3.70	29	3.1	0.3	2.75–3.92
100–150 m								
Headline height	12	5.6	0.6	4.5–6.5	12	6.4	0.4	6.0–7.2
Doorspread	12	88.0	9.1	74.5–102.0	12	83.9	4.9	74.8–89.8
Warp/depth ratio	12	2.9	0.3	2.46–3.28	12	2.6	0.2	2.30–2.9
150–250 m								
Headline height	13	5.5	0.6	4.6–6.3	20	6.2	0.4	5.7–7.0
Doorspread	13	98.5	9.1	80.0–107.0	20	92.5	7.1	74.7–103.0
Warp/depth ratio	13	2.9	0.2	2.55–3.27	20	2.5	0.2	2.29–2.86
10–150 m								
Headline height	70	5.6	0.3	4.5–6.5	58	6.3	0.3	5.9–7.6
Doorspread	70	83.5	5.4	74.5–102.0	58	83.0	3.7	73.3–89.8
Warp/depth ratio	70	6.7	3.5	2.46–17.39	58	4.4	2.7	2.30–13.79

Appendix 2: **Length-weight relationship parameters used to scale length frequencies and calculate length class biomass estimates. Source of data was NIWA *trawl* database**

$W = aL^b$ where W is weight (g) and L is length (cm)

Species code	a	b	n	Range (cm)	Raw data source
GUR	0.0037	3.2788	1197	13.4–48.3	KAH9902
JDO	0.0065	3.2499	352	18.4–54.3	KAH9902
JMA	0.0163	2.9230	200	15–40	COR9001
JMD	0.0165	2.9300	200	15–53	COR9001
JMN	0.0163	2.9230	200	15–40	COR9001
LEA	0.0088	3.2110	—	—	IKA8003
RSK	0.0346	2.8654	134	17–62	KAH9701
SNA	0.0480	2.7790	1220	12.4–62	KAH9902
TAR	0.0097	3.1702	155	19.2–48	KAH9902
TRE	0.0241	2.9345	921	21–58	KAH9304, KAH9402, KAH9502, KAH9602

— Data not available

Appendix 3: **Macroscopic condition stages of gonads of red gurnard (*after* Clearwater 1992)**

Stage	Macroscopic condition
Males	
1	Immature; testis translucent, angular threads
2	Spermatogenic; testis white, no milt in spermaducts
3	Partially spermiated; testis white, viscous milt in spermaducts
4	Mature (fully spermiated); testis white, plump, fluid milt expressable from spermaduct
5	Spent; testis bloody/grey, no milt expressable
Females	
1	Immature; ovaries small, translucent pink, no eggs visible
2	Previtellogenic/regressed; ovaries small, pink-orange granular oocytes may be visible
3	Vitellogenic; ovaries plump, pink-orange or yellow vitellogenic oocytes (~0.6 mm diameter), visible in large numbers
4	Hydrated; ovaries plump, orange red. Clear, hydrated oocytes (~1.2 mm diameter), dispersed evenly among vitellogenic oocytes characterising the previous stage
5	Mature; ovulated oocytes expressed from the oviduct when slight pressure applied to the abdomen
6	Spent; ovaries flaccid, often dark red or "bloody" in colour. Oocytes if present are unevenly dispersed. Dark brown specks or material sometimes visible

Appendix 4: **Macroscopic condition stages of gonads of John dory (*after* Hore 1982)**

Stage	Macroscopic condition
Males	
1	Virgin; testis thin and ribbon like, pale white in colour with a smooth surface
2	Developing-resting; convoluted surface, grey in colour
3	Developing; convolutions more prominent, network of blood vessels over surface, no milt runs when cut, milky white in colour
4	Ripe-spawning; convolutions of surface marked, firm to touch, pure white, prominent blood vessels, milt runs when testis is cut
5	Spent; flaccid, brown/white, no milt runs when cut
Females	
1	Virgin; ovaries thin, lie along posterior edge of ventral cavity, orange
2	Maturing virgin; ovaries enlarged, no eggs visible to the eye, orange
3	Developing; eggs visible to eye, orange with reddish tinge, network of blood vessels developing
4	Developed; eggs clearly discernable, some hyaline eggs present. Ovary fills ¼ of ventral cavity, yellow
5	Gravid; ovary fills 1/3 of ventral cavity, some transparent eggs, opaque and small yellow eggs predominate
6	Running ripe; transparent eggs expressed from ovary under slight pressure. Opaque and yellow eggs still present

7	Partly spent; not fully empty, some transparent eggs still present, hyaline and small yellow eggs predominate
8	Fully spent; ovaries flaccid and bloodshot. Some opaque and small yellow eggs visible, ovary walls purple in colour

Appendix 5: **Macroscopic condition stages of gonads of snapper (*after* Pankhurst *et al.* 1987)**

Stage	Macroscopic condition
Males	
1	Immature; testis white threads
2	Spermatogenic; testis firm and ivory white in colour
3	Partially spermiated; testis firm, ivory white in colour with viscous milt in spermaduct
4	Fully spermiated; testis firm, ivory white in colour with free flowing milt in spermaduct
5	Spent; testis spent and bloody in colour and flaccid
Females	
1	Immature or regressed; ovary clear, no oocytes visible
2	Resting; ovary pink or clear, small clear oocytes visible against the light
3	Developing; opaque orange ovary, oocytes present
4	Ripe; hyaline oocytes present
5	Ovulated; eggs flow freely when light pressure applied to abdomen
6	Spent; ovary flaccid and 'bloody', residual eggs sometimes present in oviduct

Appendix 6: **Macroscopic condition stages of gonads of tarakihi (*after* Tong & Vooren 1972)**

Stage	Classification	Histological description
Males		
0	Virgin	Oogonia and primary oocytes only
1	Resting	Oogonia and primary oocytes only
2	Developing	Oogonia, oocytes, and isolated vacuolated oocytes
3	Developing	Oogonia, oocytes. Vacuolated oocytes and small yolked eggs numerous
4	Maturing	All stages, several groups of eggs, some fully yolked and ready for ovulation, others less yolked, others vacuolated only. In some ovaries evacuated follicles are also present, which represents a partially spawned fish.
5	Ripe	As stage 4, but ovulated ripe hyaline eggs in the lumen, and evacuated follicles numerous
6	Partly spent	Evacuated follicles present and some resorption of unspawned eggs
7	Fully spent	Reserve oocytes, resorbing unovulated eggs, mitotic proliferation of oogonia
Females		
0	Virgin	Primary germ cells
1	Resting	Primary germ cells, spermatogonia, mitosis

2	Developing	All stages, sperm in lumen only, some mitosis
3	Developing	All stages, occasional mitosis, sperm extend into collecting ducts
4	Ripe	All stages, few spermatogonia, no mitosis, collecting ducts filled with sperm
5	Running	Sperm only, plus isolated primary germ cells
6	Partly spent	Partial collapse of lobules, but abundance sperm still present, erythrocytes invading tissue
7	Spent	Complete collapse of lobules, residual sperm only, massive connective tissue increase