Growth and movement of tagged kahawai in New Zealand waters

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Abstract

Griggs, L., Bradford, E., Jones, B., & Drummond, K. 1998: Growth and movement of tagged kahawai in New Zealand waters. ***NIWA Technical Report 10.*** **37 p.**

In March and June 1991, 9606 kahawai were tagged and released in Tasman Bay and the Bay of Plenty as part of an age validation study. This provided an opportunity to analyse movements, distribution, and growth of tagged fish.

A total of 1482 kahawai was returned (at 30 October 1997), 702 from fish released in Tasman Bay and 780 from the Bay of Plenty, representing an overall return rate of 15.4%. Many were recaptured close to their release sites, but several had travelled great distances. Only 8 of the 702 fish from Tasman Bay were recaptured more than 50 n. miles from their release site, and of these, 5 were recaptured more than 100 n. miles from their release site. The Bay of Plenty fish tended to disperse more: 53 of the 780 fish recaptured were more than 50 n. miles from their release site and 33 of these were more than 100 n. miles from where they were released.

Of the fish returned, 59% were from commercial catches, 38% came from recreational fishers, and for the remaining 3% the type of fisher was unknown. Purseseine was the most common commercial fishing method, and recreational fishers mainly caught kahawai by rod and line.

The tagging procedure appeared to alter the behaviour of the tagged fish, which often sought refuge in estuaries to recover from their wounds. It can not be assumed that the behaviour of the tagged fish would be the same as that of the rest of the population.

The growth rates for kahawai tagged, released in the Bay of Plenty, and returned were estimated to be 3.25 cm/y at 40 cm and 1.64 cm/y at 52 cm. No acceptable estimates of growth from the Tasman Bay tagging could be made. Analysis of growth is confounded by shrinkage that occurs on freezing of kahawai (most recaptured fish were returned frozen).

Introduction

Kahawai (*Arripis trutta*) are a schooling pelagic fish belonging to the family Arripidae, which has one genus, *Arripis* Jenyns. Four species are endemic to waters of Australia and New Zealand, *A. georgianus*, *A. trutta*, *A. truttaceus*, and *A. xylabion* (Paulin 1993). Kahawai are found in waters around the North Island, the South Island, the Kermadec Islands, and Chatham Islands in New Zealand, and in Eastern Australia, Victoria, and Tasmania (Paulin 1993), mainly in coastal seas and also in harbours, estuaries, and rivers.

The bulk of the New Zealand commercial catch is taken by purseseine vessels (Jones et al. 1992, Jones 1995), mainly from the Bay of Plenty and around Cook Strait and Kaikoura (Jones 1995). Significant quantities of kahawai are also taken by set net and trawl fisheries, mainly as bycatch.

The kahawai fishery is of importance to the New Zealand domestic purseseine fleet. The northern fleet, based in Tauranga, targets a mix of species including kahawai, jack mackerels (*Trachurus* spp.), and blue mackerel (*Scomber australasicus*) throughout much of the year. From about December to May, skipjack tuna (*Katsuwonus pelamis*) is the target species and there is little bycatch. The southern fleet, based in Nelson, fishes mainly for kahawai and mackerels, and stops fishing in mid winter (Jones 1995).

Kahawai are a popular recreational fish, especially in the north of the North Island (Jones 1995, Bradford 1996a) and in the central region (Kilner & Bell 1992), and are also an important traditional food for Maori (Kilner 1988).

Concern has been expressed by recreational fishers over the state of the kahawai fishery and the effects of commercial fishing (Feldman 1993, 1994). Recreational catch rates of kahawai are reportedly lower in the 1990s than the 1980s. Recreational fishers have raised questions about movements of kahawai between areas in an effort to explain apparent localised depletion of fish.

A tagging programme in the 1980s gave some information on kahawai movements (Wood *et al.* 1990). In 1991, 9606 kahawai were tagged and injected with oxytetracycline as part of an age validation study. This provided an opportunity for further study of movements and growth of the tagged fish.

Effects of tagging

Tagging has long been used as a means to study movements of fish and obtain information on growth (e.g., Crossland 1982). However, the tagging process is detrimental to the fish, and caution must be exercised in extrapolating results derived from tagged fish to the rest of the population.

Studies on the effects of tags show that tagging has a range of effects on kahawai and other species which can include mortality, reduced condition, a period of negative growth, retarded growth, and chronic injury affecting behaviour.

Stanley (1983) tagged Australian salmon (*Arripis trutta esper*) with a mixture of dart tags and internal tags, and found internal tags, especially those with attached streamers, to be superior to dart tags which were prone to shedding and caused wounds. Australian salmon was found to be a robust species, little affected by the stress of

tagging operations, although when fish were held under adverse conditions for long periods of time, or when open wounds were pronounced, their movement into the adult fishery was delayed.

McFarlane & Beamish (1990) found reduced growth, and a higher mortality rate for the smaller fish in tagged sablefish (*Anoplopoma fimbria*). Reduced growth in northern pike (*Esox lucius*) was attributed to the tag itself and inflammation at the tag insertion site (Scheirer & Coble 1991). Manire & Gruber (1991), using dart tags and passive integrated transponder microtags, found that dart tags inhibited growth rates of juvenile lemon sharks (*Negraprion brevirostris*), and recommended that the use of dart tags be discontinued.

Roberts *et al.* (1973a, 1973b, 1973c) have shown that the tagging process causes a severe traumatic wound which is susceptible to secondary infection and can result in mortality in Atlantic salmon (*Salmo salar*). Further, exercise was shown to cause extensive haemorrhagic necrotic wounds and loss of osmotic control around the wound and the degree of mortality was related to temperature (Morgan & Roberts 1976).

Physiological stress in response to capture (Mazeaud *et al.* 1977, Wells *et al.* 1986, Wells 1987) can cause disturbances to body chemistry, tissue breakdown (Wells 1987), and even lead to death some hours after exercise, which can probably be attributed to intracellular acidosis, and this raises questions about the validity of returning captured fish to the wild (Wood *et al.* 1983). Exposure to air after exhausting exercise is a significant additional stress which can result in delayed mortality of released fish (Ferguson & Tufts 1992).

Oxytetracycline (OTC) injected to mark otoliths in fish has been shown to cause direct mortality in sablefish, *Anoplopoma fimbria* (McFarlane & Beamish 1987). The relationship between dosage and survival of injected fish released directly into the ocean was found to be positive and strongly linear, and as even the smallest dosages caused some mortality there was no absolutely safe dosage. Laboratory studies could not be used to determine appropriate dosages because survival in the ocean of OTC injected (tagged) fish was reduced compared with those injected with OTC in the laboratory.

Methods

In March and June 1991, 9606 kahawai were tagged and released in the Bay of Plenty and Tasman Bay as part of an age validation study. The results of the age validation study were described by Stevens (1997).

Before tagging, tank trials were carried out to determine suitable types and dosage levels of OTC required to mark kahawai otoliths. Dart tags were also tested and found to be better than the loop tags used for the 1980s kahawai tagging (Wood *et al.* 1990) which caused chaffing of the skin and ulceration. Shedding is known to occur

with dart tags, but this was not considered to be a problem because the primary purpose of the tag in this programme was to provide a mark for return of the fish, and therefore the otoliths, for age validation.

The tagging programme was carried out onboard Sanford's commercial purseseine vessels, *Waihola* in Tasman Bay, and *San Columbia*, *San Tortugas*, and *Western Ranger* in the Bay of Plenty.

Each fish was measured (fork length, to the nearest millimetre for Bay of Plenty fish, and rounded down to the nearest whole centimetre for Tasman Bay fish), given a 50 mg/kg intramuscular injection of OTC (Roscocycline-5), and tagged by MAF Fisheries staff. The fish were caught and released at one site in Tasman Bay and five sites in the Bay of Plenty. Release positions, dates, and the numbers released are shown in Table 1.

Hallprint single barb, plastic-tipped, 12 cm long dart tags were used. Yellow and red tags were used in both areas to compare the rates of return based on colour. It was thought that as yellow tags are easier to see under water than red tags, yellow tagged kahawai may be subject to greater predation.

The programme was extensively advertised and rewards were offered to encourage the return of recaptured tags, and preferably the whole fish. Fish returned were measured, weighed, sexed, and assessed for general condition and status of the wound site, and otoliths were extracted for age validation.

Results

Recaptures

By 30 October 1997, 1492 of the tagged fish had been returned: 788 had been released in the Bay of Plenty and 704 in Tasman Bay. The overall return rate was 15.5% (Table 1).

Movement

The positions of the kahawai at recapture are shown in Figure 1. Most of the recapture positions were provided by recreational fishers and most are close to the shore. Kahawai are mainly found between the 200 m depth contour and the coast. Distance travelled against time at liberty is shown in Figure 2.

Most recaptured kahawai were caught in the open sea, but some were caught in rivers or in harbours or inlets (Table 2). Returns by number of days at liberty and release

length are summarised in Table 3. Recapture length plotted against distance travelled, for both sites combined and for Tasman Bay and the Bay of Plenty separately, are shown in Figure 3.

The recapture position was not available for most commercially caught kahawai. Tagged kahawai are usually discovered after vessels return to port when the catch is sorted in the sheds. It is usually not possible to determine where the vessel caught a tagged fish and transhipments often mean the vessel cannot be identified.

Fish from the Bay of Plenty moved as far north as Whangaroa and as far south as the Tukituki river in southern Hawke's Bay. Of the 788 Bay of Plenty fish, 54 (6.9%) were recaptured more than 50 n. miles from their release site, and of these 33 (4.2%) were more than 100 n. miles from their place of release. One fish was caught at Mana Island, 450 n. miles from where it was tagged. Bay of Plenty tagged fish have been found 100 n. miles or more away within 8 months of being released (Table 4). Fish from the Bay of Plenty moved both north and south.

Only 10 (1.4%) of the 704 Tasman Bay fish recaptured were more than 50 n. miles from their release site (Table 4), and of these 7 (1.0%) were more than 100 n. miles from their release site. These seven fish were recaptured 3 or more years after release. Five were caught on the west coast of the North Island, as far north as the Hokianga Harbour, and one was caught in February 1997 in the Taramakau river mouth, south of Greymouth. This is the furthest south that any kahawai has been recaptured in this survey. The most recent Tasman Bay recapture was at Simmonds Island, North Cape in March 1997. This fish was 437 n. miles from its release site, the greatest distance travelled of the fish recaptured from the Tasman Bay site.

Most of the Tasman Bay fish remained in the Tasman Bay area. Many were caught by a Tasman Bay set netter within 6 weeks of tagging, and 207 fish were caught in one purseseine shot in December 1991 (9 months after tagging), showing that at least some of these tagged fish stayed in the same schools.

Fishing methods

Returns, by area and method of recapture, and the proportion taken by recreational and commercial fishers are summarised in Table 5. Recreational fishers returned 571 fish (38% of those returned), compared with 884 from commercial fishers (59%), though 207 of these were caught in one purseseine shot. The type of fisher was unknown for 37 fish (3%).

Most recreationally caught kahawai were taken by rod and line (56%), or set net (21%). Poling or jigging (11%), trolling (4%), and set lines (1%) are also used by amateurs. The fishing method was not known for 7% of the amateur returns. One tag was found washed up on the beach.

Commercial catches were mainly by purseseiners (73%), with some commercial set netting (24%) and trawling (2%). About 1% of commercially caught fish were taken by set line, trolling, and poling or jigging (combined).

The percentages of the amateur and commercial catch taken by the main methods used in the north region (KAH 1 and 9) during 1993–94 are given in Table 6. The amateur data are from the marine recreational fishing survey (Bradford 1996a) and the commercial data are from the catch and effort database. The numbers give an indication of the expected proportion of tag returns by method from the Bay of Plenty releases. Much of the commercial kahawai catch, other than purseseine, is taken as bycatch and the proportions by method vary from year to year.

Seasonality

Returns by month of recapture are shown in Table 7. A breakdown of amateur and commercial returns by month and year is given in Table 8, and a summary of returns by month and area in Table 9.

Commercial catches of tagged kahawai were made throughout the year, mainly between April and August in the northern region: in the southern region, fishing ceased in mid winter. Most recreational catches of tagged kahawai were in summer when most of the recreational fishing effort occurs. The ratio of summer to winter fishing effort in the northern region, taken from the marine recreational fishing survey, is 4.2 (Bradford 1996b). The ratio of summer to winter effort in the Bay of Plenty, based on the tag returns from summer 1991 through to winter 1995 (four complete seasons), is 2.9 (*see* Table 8).

Comparisons of tagged and untagged fish in Tasman Bay

At tagging

About 30 t of kahawai caught for tagging were subsequently landed into Sanford's, Nelson and the catch was measured in the factory. The length frequency of the tagged fish compared with a sample of this landed catch is given in Table 10.

The tagged kahawai were slightly larger than the landed kahawai. A chi-square test, with the null hypothesis that the tagged fish are a random sample from the sample population, was rejected. A second chi-square test, testing the null hypothesis that the landed kahawai were 0.5 cm shorter than the tagged kahawai, was not rejected. Fish tagged were selected as being in good condition and free of any noticeable scale loss, and there was no conscious decision to select larger fish.

After tagging

FV *Shemara* captured 207 tagged kahawai in one purseseine shot on 16 December 1991. The net was reported to have surrounded at least three separate schools, and 135 t were landed. As part of a (MAF) sampling programme, 185 tagged kahawai were measured along with 834 untagged ones. The size distribution is shown in Table 10.

The tagged fish show a similar size distribution for the 3+ year old cohort, except that the modal length for the untagged fish is 41 cm, and for the tagged fish 39 cm. This suggests that tagging affected growth of this cohort. The modal length of the fish when measured live in March was 38 cm.

Samples of both tagged and untagged fish were also weighed. Length–weight relationships were calculated using the geometric mean functional relationship

$$\text{tagged weight} = 0.00002100 \times \text{length}^{2.911}$$

$$\text{untagged weight} = 0.00001257 \times \text{length}^{3.086}$$

where length is in centimetres and weight in kilograms.

For any given length, the tagged kahawai weighed less than the untagged fish, suggesting a poorer condition index.

Change in tagging mortality with holding time in Tasman Bay

In Tasman Bay, the kahawai came from one school and the tagging of 4984 fish was done in one afternoon. Concern has been expressed about the physical state of the kahawai, especially those tagged late in the day. Plots of the time at liberty and growth against hour of tagging show that the number of fish returned decreased as the time the kahawai were held before tagging increased, but the spread of values of time at liberty and growth did not (Figure 4). The 207 kahawai recaptured in a single purseseine set in December 1991 had been tagged throughout the day and appear as a line of points at a time of liberty of about 0.7 years.

To quantify the change in return rate with hour of tagging in the Tasman Bay experiment, the number of tags applied in each hour and the number which were returned from each hour of tagging were compared (Table 11). The percentage of returns to releases for fish tagged and released in each hour of the experiment dropped from 22.5% for the first hour to 5.5% for the last full hour. Hence it seems that kahawai tagged later in the day were more likely to die soon after tagging than those tagged earlier in the day, and fish which did survive had much the same growth pattern, irrespective of the hour of tagging.

Movement of kahawai into estuaries

The catches of a commercial set netter targeting yelloweyed mullet in the Waimea estuary (southern Tasman Bay) unexpectedly changed to include numbers of kahawai within days of the tagging event in Tasman Bay. The catch was sampled and 200 tagged kahawai and 490 untagged kahawai were measured between March 1991 and February 1992. Most of the 3+ year old kahawai caught were tagged and most of the untagged fish were 2+ years old.

Shrinkage

Most of the recaptured tagged kahawai were frozen before being sent to Wellington for measurement. Irreversible shrinkage with freezing results in apparent "negative growth", and this complicates analysis of growth, especially for fish recaptured within the first few months of tagging. Shrinkage in frozen salmon (*Salmo salar*) affected all fish and was related directly to the fresh length (Armstrong & Stewart 1997).

A total of 385 fresh kahawai bearing tags was returned to the Nelson MAF office and measured. These fish were frozen and then sent to MAF Fisheries at Greta Point (Wellington) where they were again measured after thawing. Figure 5 shows length measured fresh (Nelson measurements) against length measured after freezing (Greta Point measurements). The regression line is added to the plot

fresh length = 0.962 (*s.e.* 0.013) x frozen length + 1.036 (*s.e.* 0.495) cm

The regression line showed no significant variation with length in the release length size range (33–43 cm): the average shrinkage was 0.71 cm (*s.e.* 0.016).

A sample of 58 kahawai was caught around Wellington. These were measured alive, then measured again after freezing and thawing (the same people measured the fish at all stages). The size range was 28–55 cm. Most of the fish were thawed and measured at an intermediate time, and this made little difference to the overall length change. Shrinkage (S) or negative growth, the overall length change for each fish, is plotted against original length (L) in Figure 6. The regression line added to the plot

$$S = -0.23 \text{ (s.e. } 0.25) - 0.022 \text{ (s.e. } 0.006)\ L$$

suggests that shrinkage increases with length.

Growth parameters from length increments

Bay of Plenty

The program GROTAG estimates the growth rate at two selected lengths within the range of the data and variability and bias parameters (*see* Francis 1988 for parameter definitions and the fitting procedure).

Of the kahawai tagged and released in the Bay of Plenty in 1991, 560 were returned with length measurements on release and recovery. Most of the fish were frozen and thawed before measurement and had shrunk in the process. The expected shrinkage is 1–2 cm and all fish which shrank more than 2 cm were removed from the analysis. All records where the apparent growth was such that the data gave a large positive outlier in the GROTAG run were removed. The pruned sample contained 510 data points with release lengths between 34.9 and 56.5 cm. Growth rates at 40 cm and 52 cm, growth variability, measurement error, and bias were all estimated (Table 12). The large bias term (–1.27 cm) will be mainly due to shrinkage. This will be an approximation as shrinkage is probably length dependent.

Adding seasonal growth factors to the model gave no significant improvement. Allowing different growth rates for males and females gave only small differences. A modification of GROTAG (Francis 1995) which allows a non-linear growth rate gave no significant improvement. It is possible that the data are too noisy to detect such differences.

The standard errors from the fit show no abnormal distributional features when plotted against time at liberty and length at tagging (Figure 7). The standard errors did show a marked trend without the bias correction term in the model. Errors on the estimated parameters are found by re-sampling the data (500 times) and calculating standard deviations of the parameter distributions so obtained. The re-sampling distributions of the parameters looked normal and showed no obvious bias.

Comparison with growth rates from age and length

Several age and length data sets are available for kahawai and von Bertalanffy parameters have been estimated (McKenzie *et al.* 1992, Drummond & Wilson 1993, Drummond 1995, Stevens 1997). The interpretation of the von Bertalanffy parameters is somewhat different from that used in GROTAG. However, growth rates were calculated at 40 and 52 cm from the relations given by McKenzie *et al.* (1992) for the Bay of Plenty: g_{40} (the growth rate at 40 cm) was 3.612 cm/y for females and 3.331 cm/y for males and g_{52} was 1.052 cm/y for females and 0.770 cm/y for males. The GROTAG values are g_{40} = 3.247 cm/y and g_{52} = 1.639 cm/y. GROTAG gave a lower value for the growth rate at 40 cm and a higher value at 52 cm than calculations from the age and

length data. Some of the apparent differences in growth rate may stem from the different parameter interpretations in the two model formulations. The von Bertalanffy equation with constant parameters may not describe the growth adequately.

Tasman Bay

Of the kahawai tagged and released in Tasman Bay in 1991, 569 have been returned to date with length measurements available on release and recovery.

A good fit to the data using GROTAG has not been possible. The tagged kahawai were from a single school with lengths between 32 and 44 cm (90% between 35 and 40 cm). Pruning the data (removing large negative growth and large positive outliers) and running GROTAG gave growth rates at 35 and 40 cm which were abnormally low. This is to be expected as most of the fish were recovered in the first year and most were in poor condition and had not grown. The residuals for those fish which survived more than a year were positively biased. Removing recoveries made in 1991 left 84 data points. These gave growth rates of about the expected size, but the growth at 40 cm was greater than the growth at 35 cm (possible if the larger fish were better able to withstand the stress of being tagged). Less drastic removals of data gave acceptable parameter estimates but did not remove the positive bias in the residuals of the data from kahawai that had been at liberty for more than 1 year.

There are two extremes: those kahawai that survived the stress of being tagged and grew normally and those that had severely retarded growth rates and probably died within the first year after tagging. Of course, some fish would have been between these two extremes. No simple way of separating the kahawai with "normal" growth rates has been found. No adequate description of growth was obtained from GROTAG because only a narrow size range of fish was available.

Tag colour

It was thought that as yellow tags are easier to see under water than red tags, yellow tagged kahawai may be subject to greater predation. Increased predation in response to colour has been seen in brightly coloured prey (Metz & Ankney 1991).

There was no significant difference in return rates for the two colours ($p = 0.5$, chi-square test, using the total numbers for each colour). The number of red tags returned from the Bay of Plenty (19.5%) was greater than the number of red tags returned from Tasman Bay (12.7%). The numbers returned and the percentages are shown in Table 13.

Discussion

By 30 October 1997, 1492 of the 9606 tagged kahawai (15.5%) had been returned. An earlier summary of the data shows that 1448 (15.1%) had been returned by November 1994 (Griggs 1995). This return rate is much higher than that of the kahawai tagging survey conducted between October 1981 and February 1984 to study movements: 13 911 tagged fish were released at 27 sites around the North and South Islands and 1190 (8.6%) were returned (Wood *et al.* 1990).

The higher return rate of the 1991 survey is likely to be a reflection of the increased awareness of tagging programmes and the concentration of tagging in two areas of high recreational and commercial catch. Areas of high catch were chosen as release sites to ensure high returns for the age validation study.

The percentage returned from the Bay of Plenty (17.0%) was higher than for Tasman Bay (14.1%). The latter group of 4984 fish were all tagged in one afternoon, and those held in the net for a prolonged period suffered considerable stress, as can be seen by the reduction in return rate according to release order. The fish released in Tasman Bay appeared to be healthy on release, but many of these fish were recaptured in poor condition with large infected wounds.

Many of the tagged fish were recaptured close to where they were released, although there is no way of knowing how far they travelled in their time at liberty. Several travelled up to 450 n. miles between the places of release and recapture. The Bay of Plenty fish tended to disperse more than the Tasman Bay fish.

Many Tasman Bay fish remained in the Tasman Bay area. The difference in dispersal between the two groups, and the capture of Tasman Bay fish in harbours or inlets, seems to be largely due to different sizes at tagging. The Tasman Bay fish had an average length at tagging of 37 cm compared with 46 cm in the Bay of Plenty. This suggests that kahawai tend not to travel far from their nursery areas until they are adults, and that smaller fish may suffer more from tagging. Tasman Bay has been shown to be an important nursery area for juvenile kahawai (Drummond 1994). Wood *et al.* (1990) also noted this and recorded a smaller mean length for kahawai sampled in this area than in other areas sampled. Drummond (1994) showed size related movement of kahawai from estuarine to open waters in their fourth year. Size specific migration has also been observed in Australian kahawai (Malcolm 1960, Stanley 1978).

Many of the fish that were recaptured in the 1980s study were caught close to where they were tagged, but some of the fish had travelled great distances (Wood *et al.* 1990). Of 140 fish tagged in Tasman Bay, only 5were recaptured, all in Tasman Bay. In the Bay of Plenty, 1434 fish were released and 137 were recaptured: 90 were caught in the Bay of Plenty, 14 travelled north, 20 were caught in Hawke Bay, and 13 were found further south, including 1 recaptured near Kaikoura (Wood *et al.* 1990).

Recreational fishers caught 38% of the tagged fish returned, compared with 59% commercially caught fish. Most recreationally caught kahawai were taken by rod and line, and commercial catches were mainly by purseseiners. The figures for tag capture by method are roughly proportional to commercial and recreational catch by method, except for a disproportionately large number of fish caught by set net. Many of the set net catches occurred in the early stages when fish were apparently seeking refuge in estuaries in response to their wounds.

It must also be remembered when looking at where tagged fish were caught, that fishing effort is not uniform throughout the country. A seeding experiment suggested that 30% of the tagged fish recaptured by purseseine vessels were not recovered (Wood *et al.* 1990).

Comparisons of tagged and untagged kahawai from a purseseine catch after tagging showed that the tagged fish were shorter, suggesting that tagging affected growth, and for any given length, the tagged kahawai weighed less than the untagged fish suggesting a poorer condition index.

A trial conducted before the main tagging programme in 1981–84 showed that tagged fish had a higher mortality rate in the short term than untagged fish, probably as a result of extra handling rather than tagging (Wood *et al.* 1990). Increased mortality with holding time in the Tasman Bay fish showed that additional handling and stress imposed on the fish decreased their chances of survival after release.

The catches of a commercial set netter targeting yelloweyed mullet in the Waimea estuary showed that most of the 3+ year old kahawai caught were tagged fish and most of the untagged fish were 2+ years old. Kahawai move out of estuarine waters in their fourth year (Drummond 1994) which is why few untagged 3+ years kahawai were caught in the estuary. The size differential between the 3+ years kahawai caught in the estuary and "offshore" kahawai caught by purseseine is also indicative of size-related movement from estuarine to open water in the fourth year.

The commercial yelloweyed mullet fisher rarely caught kahawai until the tagged kahawai were released in Tasman Bay, at which time he began to catch many kahawai. This suggests that untagged fish were schooling with the injured tagged fish which moved into the estuary.

Fish may exhibit a fever response (or behavioural thermoregulation), in which an infected fish will select a favourable elevated temperature within its environment, such as an estuary. Raising a fish's internal temperature assists the effectiveness of the immune response to infection, and significantly enhances survival in infected fish (Reynolds *et al.* 1976, 1978, Reynolds 1977, Covert & Reynolds 1977, Kluger 1978).

Injured kahawai have been observed to move into "hospital" areas (Brent Wood, NIWA, Greta Point, pers. comm., Clive Stanley, CSIRO, Hobart, pers. comm.). A large

number of tagged Tasman Bay fish were recaptured in estuaries or inlets and they may have been seeking refuge in the estuary in response to the tagging process and the resulting wound. If so, the behaviour of the tagged fish would have been different to that of the untagged (unwounded) fish.

Growth rates for 40 and 52 cm fork length kahawai tagged, released in the Bay of Plenty, and returned, were estimated using GROTAG. The shrinkage was allowed for by using a constant negative bias term; this is a compromise if shrinkage is length dependent as indicated by the experimental data using kahawai with a wide length range caught around Wellington. Adding seasonal growth to the model did not improve the fit. The estimated growth rates differ from the published values for other kahawai samples.

The GROTAG fits to the Tasman Bay tagged kahawai were unsuccessful in that it was not possible to remove some biases from the residuals. Some of the problem is probably due to the narrow size range used. Some of the bias may be because some fish suffered more from the tagging stress than others. No way of separating the fish which suffered less stress was found.

Shrinkage occurs on freezing of kahawai and complicates analysis of growth. The amount of shrinkage appears to increase with length. Different accuracy of length measurements in Tasman Bay and the Bay of Plenty further complicated analysis of growth.

Other types of tags would be needed to give better information on movement. In particular, archival tags can give continuous ongoing positional information and detect any seasonal patterns.

Both of the release sites in this survey were in areas where purseseine catches are high and we have no information on movement into these areas. We have some information on movement out of these areas.

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Table 1: Summary of release and recapture data from the 1991 kahawai tag survey

Tag site	Position: Latitude (° 'S)	Position: Longitude (° 'E)	Date released (1991)	Number released	Number returned	% returned
TASB001	41 10	173 10	18 Mar	4 984	704	14.1
BPLE001	37 39	176 28	19 Jun	200	38	19.0
BPLE002	37 47	176 45	21 Jun	1 423	199	14.0
BPLE003	37 47	176 40	21 Jun	362	26	7.2
BPLE004	37 51	176 55	27 Jun	453	66	14.6
BPLE005	37 50	176 54	27 Jun	2 184	459	21.0
BPLE total				4 622	788	17.0
All sites				9 606	1 492	15.5

Table 2: Summary of returns by place of recapture

Place found	Tasman Bay	Bay of Plenty
River or river mouth	70	114
Harbour or inlet	295	39
Elsewhere	337	587

Table 3: Summary of returns by number of days at liberty and release length

Number of days at liberty	(months)	Release length (cm)							
		Not meas.	25–29.9	30–34.9	35–39.9	40–44.9	45–49.9	50–54.9	55–55.9
1–30	(1)	7		7	101	16	19	5	
31–60	(2)	8		3	58	20	11	5	
61–90	(3)	5		1	28	13	9	5	
91–120	(4)	2			16	9	5		
121–150	(5)	3			6	6	5	1	
151–180	(6)	1			12	6	3		
181–210	(7)	4			24	13	4	1	
211–240	(8)	6			22	6	10	2	
241–270	(9)	12		2	37	13	5	2	
271–300	(10)	21		3	202	33	9	11	3
301–330	(11)	5		2	21	11	8	2	
331–360	(12)	15		2	18	65	24	6	1
361–390	(13)	11		2	9	40	20	7	1
391–420	(14)	5			11	7	16	15	1
421–450	(15)	1			5	4	4		
451–480	(16)	3			1		5	3	
481–510	(17)	3				5	4	2	
511–540	(18)	2		1	5	6	5	6	
541–570	(19)	1			5	9	2	1	
571–600	(20)	1			1	6	2		
601–630	(21)	1			9	3	1		
631–660	(22)	1			4	4		1	
661–690	(23)				9	3	6	2	
691–720	(24)	2		1	2	2	4	1	
721–750	(25)				3	2	5	5	
751–780	(26)	2			2	16	12	8	
781–810	(27)				2	1	3	3	
811–840	(28)	1			3	3	3	3	
841–870	(29)	1				2	3	1	
871–900	(30)				2	3	3	2	
901–930	(31)				1	3		1	
931–960	(32)				2		1		
961–990	(33)	1			2		1		
991–1020	(34)				3	2			
021–1050	(35)	1			2	2	1		
051–1080	(36)				2		1		1
1081–1110	(37)				1	1	3		
1111–1140	(38)				1		1		
1141–1170	(39)				1				
1171–1200	(40)	1				1			
1201–1230	(41)	1				3	2	2	
1231–1260	(42)								
1261–1290	(43)								
1291–1320	(44)					1			
1321–1350	(45)				1	2			
1350–1380	(46)	1				1		2	
1381–1410	(47)						1	1	
1411–1440	(48)				1			1	
1441–1470	(49)	2				1			
1471–1500	(50)	1							
1501–1530	(51)				1				
1531–1560	(52)								
1561–1590	(53)								
1591–1620	(54)								
1621–1650	(55)								
1651–1680	(56)					1			
1681–1710	(57)						1		
1711–1740	(58)							2	
1741–1770	(59)				1				
1771–1800	(60)				1		1	2	

Table 3–continued

Number of days at liberty (months)		Release length (cm)							
		Not meas.	25–29.9	30–34.9	35–39.9	40–44.9	45–49.9	50–54.9	55–55.9
1801–1830	(61)								
1831–1860	(62)	1							
1861–1890	(63)								
1891–1920	(64)								
1921–1950	(65)					1			
1951–1980	(66)								
1981–2010	(67)				1				
2011–2040	(68)						1		
2041–2070	(69)								
2071–2100	(70)								
2101–2130	(71)								
2131–2160	(72)				1				
2161–2190	(73)								
2191–2220	(74)				1				
2221–2250	(75)								
2251–2280	(76)						1		
2281–2310	(77)						1		
No. tagged		**714**	**2**	**247**	**4 500**	**1 717**	**1 428**	**931**	**67**

Table 4: Summary of returns by distance travelled and time at liberty

Bay of Plenty

No. of days at liberty (months)		Distance travelled (n. miles) 1–25	26–50	51–75	76–100	101–125	126–150	151–175	176–200	201–225	226–250	251–275	276–300	301–325	...426–...450
1–60	(2)	53	8	2											
61–120	(4)	26	18	1											
121–180	(6)	17	5												
181–240	(8)	14	20	1		1						1			
241–300	(10)	16	7	1	3	1	1				2				
301–360	(12)	11	3	2		1		1							
361–420	(14)	6	1	1			3					2			
421–480	(16)	8			1						3				
481–540	(18)	7	5	2	1			1							
541–600	(20)	13	3	1	2		1				1				
601–660	(22)	4	3	1							1				
661–720	(24)	9	1					1			1				
721–780	(26)	2	1												
781–840	(28)	4	1						1		2				
841–900	(30)				1							1			
901–960	(32)	3	1												
961–1020	(34)	1						1							
1021–1080	(36)										1				
1081–1140	(38)	1													
1141–1200	(40)														
1201–1260	(42)														
1261–1320	(44)	1													
1321–1380	(46)	2	4									1			
1381–1440	(48)		2												...1
1441–1500	(50)	2	1								1				
1501–1560	(52)														
1561–1620	(54)														
1621–1680	(56)										1				
1681–1740	(58)	2					1								
1741–1800	(60)	2													
1801–1860	(62)														
1861–1920	(64)														
1921–1980	(66)														
1981–2040	(68)		1	1											
2041–2100	(70)														
2101–2160	(72)														
2161–2220	(74)														
2221–2280	(76)	1													
2281–2340	(78)		1												

Table 4–continued

Tasman Bay

Number of days at liberty (months)		Distance travelled (n. miles)													
		1–25	26–50	51–75	76–100	101–125	126–150	151–175	176–200	201–225	226–250	251–275	276–300	301–325	326–350	...426–...450
1–60	(2)	181														
61–120	(4)	47	1													
121–180	(6)	16	2													
181–240	(8)	47	1													
241–300	(10)	281	1													
301–360	(12)	30	6													
361–420	(14)	17		1												
421–480	(16)	4	2													
481–540	(18)		1													
541–600	(20)	4	2													
601–660	(22)	10	4													
661–720	(24)	12														
721–780	(26)	1	1													
781–840	(28)	1	2	1												
841–900	(30)	1														
901–960	(32)	1	2													
961–1020	(34)	6														
1021–1080	(36)		3				1									
1081–1140	(38)							1			1					
1141–1200	(40)				1											
1201–1260	(42)															
1261–1320	(44)															
1321–1380	(46)															
1381–1440	(48)														1	
1441–1500	(50)															
1501–1560	(52)	1														
1561–1620	(54)															
1621–1680	(56)															
1681–1740	(58)															
1741–1800	(60)		2													
1801–1860	(62)															
1861–1920	(64)															
1921–1980	(66)														1	
1981–2040	(68)															
2041–2100	(70)															
2101–2160	(72)									1						
2161–2220	(74)															...1

Table 5: Summary of returns by area and method of recapture

Amateur

	Fishing method						
Area	RL	SN	SL	TR	PJ	OT	Total
?						6	**6**
002	1						**1**
003	1						**1**
006	1	1					**2**
007	3	1				1	**5**
008	5					1	**6**
009	120	17		7	4	13	**161**
010	34	56			5	5	**100**
011	4						**4**
012	1						**1**
013	4	6			1	1	**12**
014	3	2			1		**6**
017	1	2					**3**
034	1						**1**
036	1						**1**
038	137	36	5	12	52	14	**256**
039	2						**2**
041	1						**1**
046	1			1			**2**
Total	**321**	**121**	**5**	**20**	**63**	**41**	**571**

Commercial

	Fishing method							
Area	PS	SN	SL	TR	PJ	TL	OT	Total
?	410		1				1	**412**
007		4						**4**
009	29	2	2					**33**
010		5		2	1			**8**
038	207	205				14		**426**
041			1					**1**
Total	**646**	**216**	**4**	**2**	**1**	**14**	**1**	**884**

Unknown

	Fishing method			
Area	SN	PJ	OT	Total
?			21	**21**
009			5	**5**
010			2	**2**
038	1	3	4	**8**
042			1	**1**
Total	**1**	**3**	**33**	**37**

RL, Rod & line
SN, Setnet
SL, Set line
TR, Troll
PJ, Poling/spinning/jigging
PS, Purse seine
TL, Trawl
OT, Other/unknown

?, Area unknown

Table 6: Recreational and commercial catch, by method

Percentage of kahawai caught by recreational fishers using the main kahawai fishing methods (from the marine recreational fishing survey in 1993–1994 by the Ministry of Agriculture and Fisheries)

Method	% catch
Private boat, line	54
Charter boat, line	5
Private boat, troll	11
Shore, line	24
Netting	6

Percentage of kahawai caught by commercial fishers, by method, for the 1993–1994 fishing year in areas KAH 1 and 9 (from estimated catch by method)

Method	% catch
Purseseine	56
Set net	15
Beach seine	9
Ring net	6
Trawl	6
Other	8

Table 7: Summary of returns by month of recapture

Bay of Plenty

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991							46	41	23	17	14	12	**153**
1992	27	16	21	57	70	75	94	24	11	8	23	14	**440**
1993	16	3	5	10	10	13	28	22	4	11	12	4	**138**
1994	1	2	0	5	3	3	2	0	0	10	0	0	**26**
1995	1	2	5	2	1	3	1	0	0	0	0	0	**15**
1996	1	1	2	0	3	0	1	0	0	0	0	1	**9**
1997	1	0	0	0	0	0	0	0	2	0			**3**

Tasman Bay

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991			19	146	30	17	18	12	15	26	39	249	**571**
1992	24	14	10	13	5	3	0	1	5	2	7	7	**91**
1993	8	3	2	1	2	2	0	1	1	1	4	3	**28**
1994	2	2	1	1	1	0	0	0	0	0	0	0	**7**
1995	0	1	0	0	1	0	0	0	0	0	0	0	**2**
1996	1	1	0	0	0	1	0	0	0	0	0	0	**3**
1997	0	1	1	0	0	0	0	0	0	0			**2**

Table 8: Breakdown of amateur (A) and commercial (C) returns by year

Bay of Plenty

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	A							16	32	21	16	12	11	**108**
	C							30	5	1	1	1	1	**39**
1992	A	21	12	11	18	8	9	4	6	6	7	6	9	**117**
	C	6	2	0	39	60	66	90	18	5	1	16	5	**308**
1993	A	16	3	5	9	4	1	1	2	4	2	1	4	**52**
	C	0	0	0	0	5	12	27	20	0	9	11	0	**84**
1994	A	0	2	0	2	0	0	1	0	0	0	0	0	**5**
	C	1	0	0	3	3	3	1	0	0	10	0	0	**21**
1995	A	1	2	5	2	1	3	1	0	0	0	0	0	**15**
	C	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1996	A	1	1	2	0	1	0	0	0	0	0	0	1	**6**
	C	0	0	0	0	2	0	1	0	0	0	0	0	**3**
1997	A	1	0	0	0	0	0	0	0	0	0			**1**
	C	0	0	0	0	0	0	0	0	2	0			**2**

Tasman Bay

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	A			6	9	11	9	18	6	11	17	35	20	**142**
	C			13	137	16	8	0	3	3	9	4	229	**422**
1992	A	22	13	9	12	5	3	0	1	5	2	7	7	**86**
	C	2	1	1	0	0	0	0	0	0	0	0	0	**4**
1993	A	7	3	2	1	2	2	0	1	1	1	4	3	**27**
	C	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1994	A	2	2	0	0	1	0	0	0	0	0	0	0	**5**
	C	0	0	0	1	0	0	0	0	0	0	0	0	**1**
1995	A	0	1	0	0	1	0	0	0	0	0	0	0	**2**
	C	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1996	A	1	1	0	0	0	1	0	0	0	0	0	0	**3**
	C	0	0	0	0	0	0	0	0	0	0	0	0	**0**
1997	A	1	1	0	0	0	0	0	0					**2**
	C	0	0	0	0	0	0	0	0					**0**

Table 9: Summary of returns by month and area

Bay of Plenty

Year	Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	?							3	7				1	**11**
	009							31	4	7	11	10	8	**72**
	010							11	30	16	6	4	2	**69**
	014												1	**1**
1992	?	6	1	10	38	61	66	88	18	5	1	16	6	**316**
	006				1									**1**
	007					2	1	2			1			**6**
	008		1	1	1							1		**4**
	009	17	13	5	13	6	6	2		3	4	5	7	**81**
	010	3	1	3	3	1	2	1	3	1	1	1	1	**21**
	011			1				1		1				**3**
	012	1												**1**
	013				1				1	1	1			**4**
	014			1					2					**3**
1993	?					5	11	27	20		9	11		**83**
	003				1									**1**
	007	2					1							**3**
	008	1										1		**2**
	009	9	2	4	6	2	1		2	1	2		3	**32**
	010	2	1	1	2	3		1		1				**11**
	011	1												**1**
	013	1			1					2				**4**
	014												1	**1**
1994	?	1			3	3	3	1			10			**21**
	009		1					1						**2**
	010		1											**1**
	013				2									**2**
1995	009		1	4		1	2							**8**
	010	1	1		1		1							**4**
	013							1						**1**
	014			1										**1**
	039				1									**1**
1996	?					1		1						**2**
	006			1										**1**
	009					1								**1**
	010		1	1		1							1	**4**
	013	1												**1**
1997	009	1								2				**3**

?, Area unknown

Table 9– continued:

Tasman Bay

Year	Area	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1991	038			19	146	30	17	18	12	15	26	39	249	**571**
1992	?				1					1				**2**
	017				1					1				**2**
	038	24	14	10	11	5	3	0	1	3	2	7	7	**87**
1993	017						1							**1**
	036						1							**1**
	038	8	3	2	1	2			1	1	1	4	3	**26**
1994	038	2	1											**3**
	039					1								**1**
	041		1		1									**2**
	042			1										**1**
1995	038					1								**1**
	046		1											**1**
1996	038	1	1											**2**
	046						1							**1**
1997	002			1										**1**
	034		1											**1**

Table 10: Length frequency data for kahawai when tagged and a sample of the landed *Shemara* catch (Number of kahawai at tagging), and tagged kahawai recaptured by *Shemara* and untagged landed kahawai from the same catch (Number of kahawai after tagging)

Fork length (cm)	Number of kahawai at tagging		Number of kahawai after tagging	
	tagged	untagged	tagged	untagged
26	1			6
27				28
28	1			66
29				88
30	1			123
31	2			83
32	22	3		50
33	64	16		13
34	149	27		2
35	364	43		
36	763	89	9	3
37	1 285	156	18	3
38	1 313	96	53	8
39	608	31	57	39
40	155	10	30	95
41	30		8	94
42	21		3	65
43	11		3	22
44	8		2	10
45	1		2	15
46				13
47				12
48				6
49	1			2
50				3
51				
52				1
Total	4 800	471	185	850

Table 11: Number of tags applied in hourly intervals in the Tasman Bay tagging (releases) and the number returned and percentage returns

Time period	Releases	Returns	
		No.	%
1230–1329	794	179	22.5
1330–1429	634	125	19.7
1430–1529	674	125	18.5
1530–1629	588	79	13.4
1630–1729	699	79	11.3
1730–1829	826	76	9.2
1830–1929	667	37	5.5
1930–1947	102	4	3.9

Table 12: Kahawai growth rates at 40 and 52 cm. The data come from kahawai tagged in the Bay of Plenty in 1991. The parameters are defined in Appendix 1

Parameter		Value	*s.e.*	Units
Growth at 40 cm	g_{40}	3.247	0.011	cm/y
Growth at 52 cm	g_{52}	1.639	0.008	cm/y
Growth variability	v	0.288	0.012	
Measurement error	s	0.598	0.007	cm
Bias	b	–1.266	0.012	cm
Outlier probability		0.062		

Table 13: Number of returns by tag colour and the percentages of those released

	Yellow		Red	
	No.	%	No.	%
Tasman Bay	325	16.3	379	12.7
Bay of Plenty	432	15.5	356	19.5
Both areas	757	15.8	735	15.2

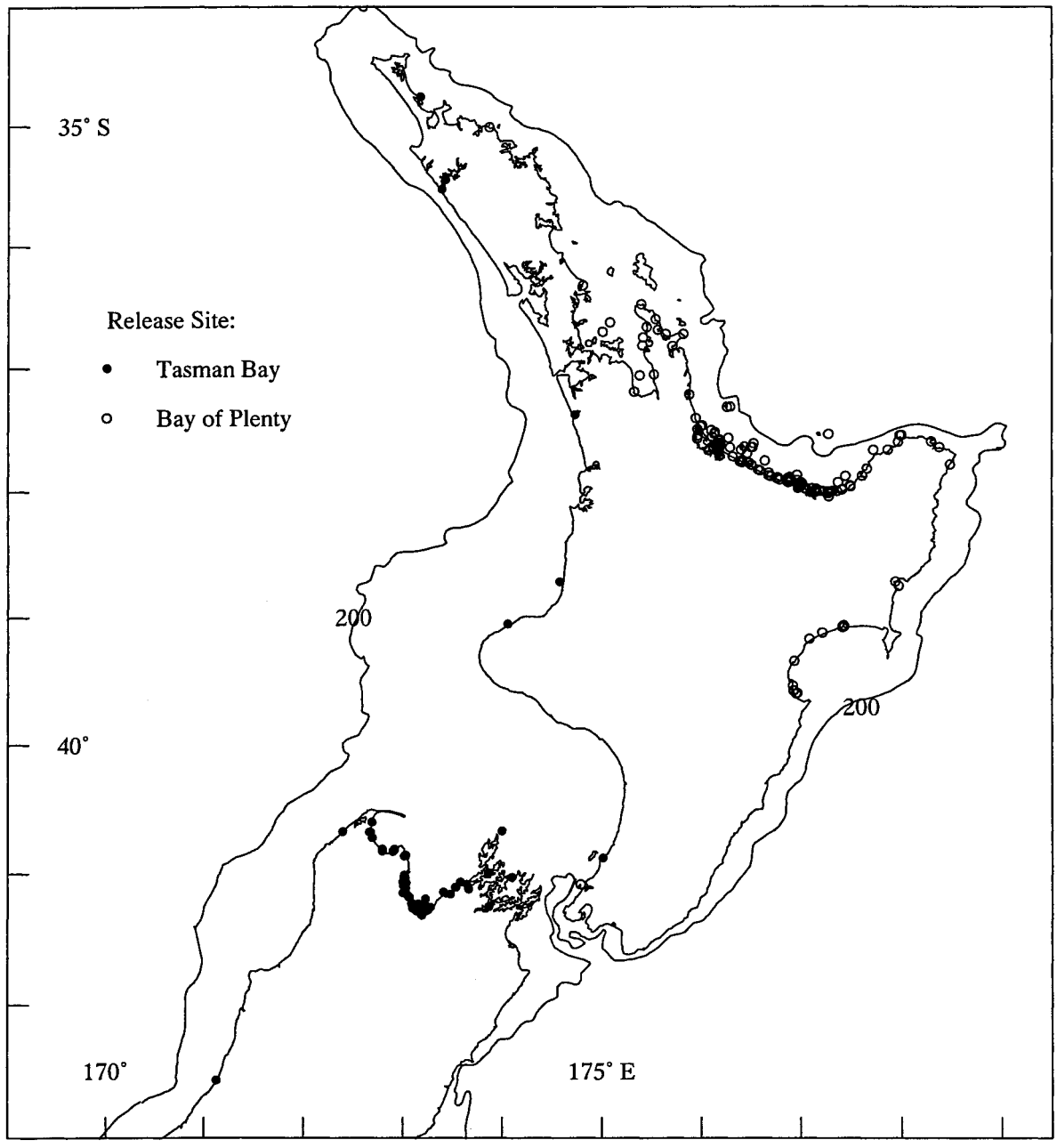

Figure 1: **Kahawai tag return sites differentiated by release site. Most of these returns are from recreational fishers and the tagged kahawai tend to have been caught close to shore. Kahawai are mainly found between the 200 m depth contour and the coast.**

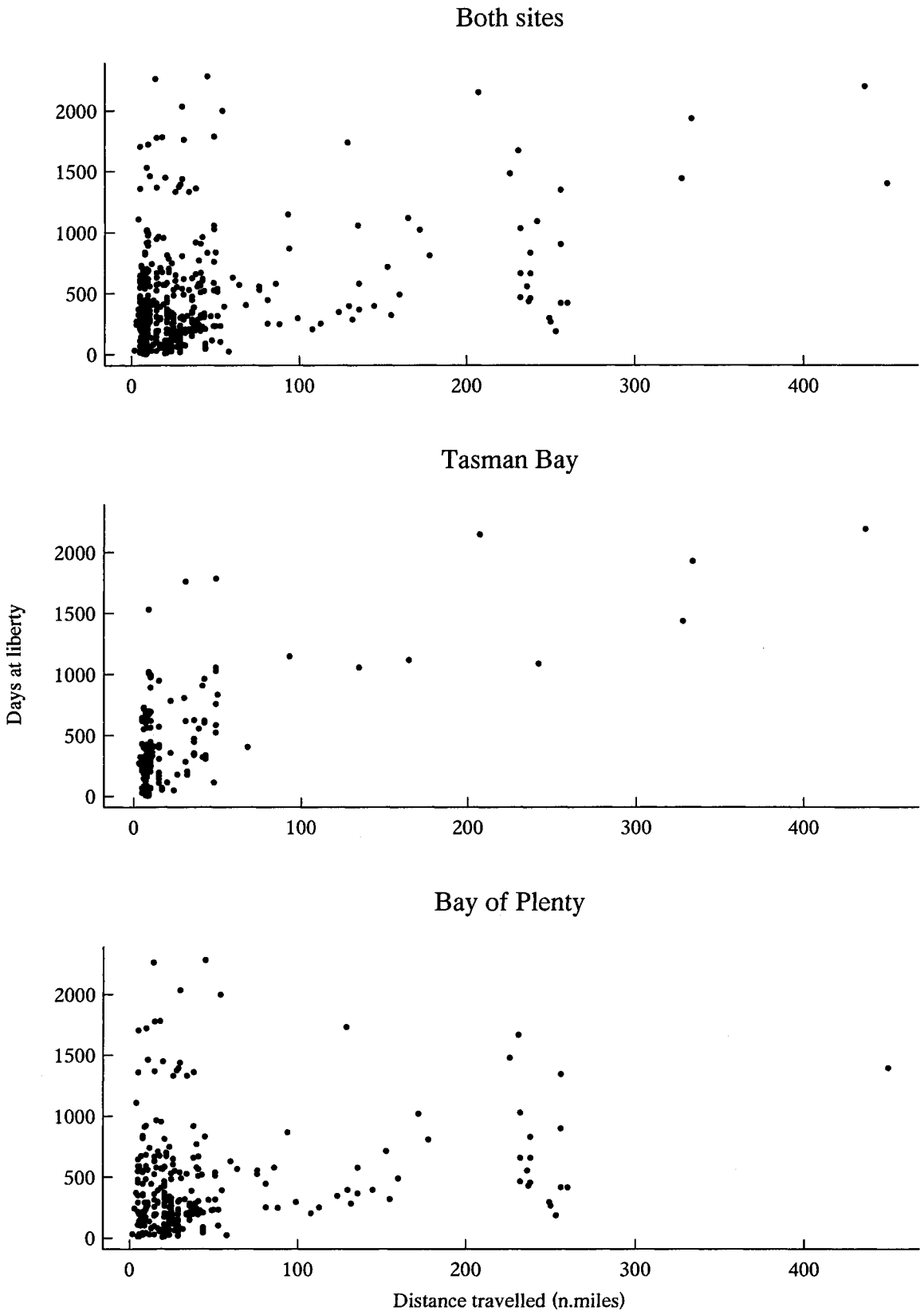

Figure 2: **Distance travelled against time at liberty, excluding recaptures within 30 days of release.**

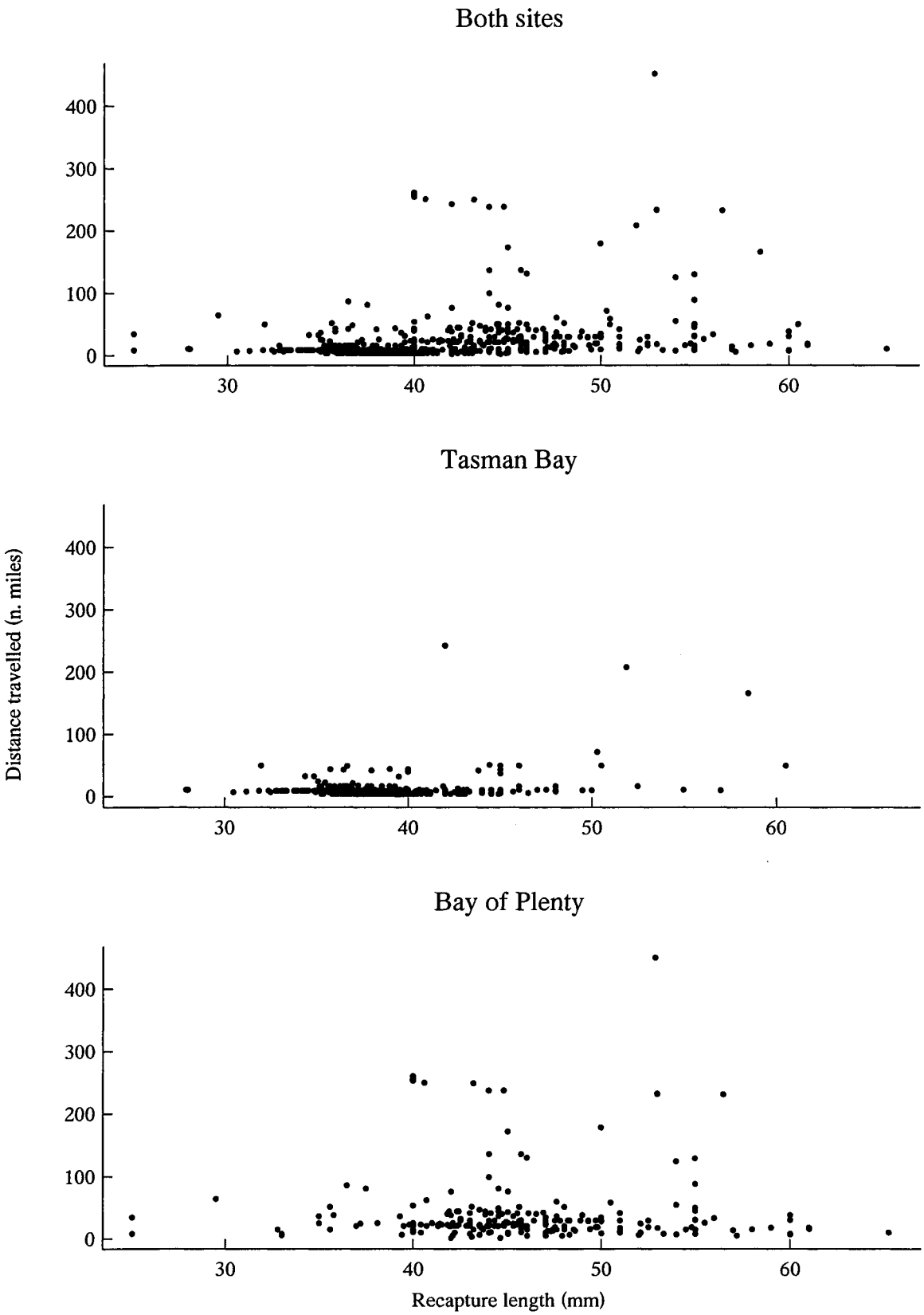

Figure 3: **Length at recapture against distance travelled, excluding recaptures within 30 days of release.**

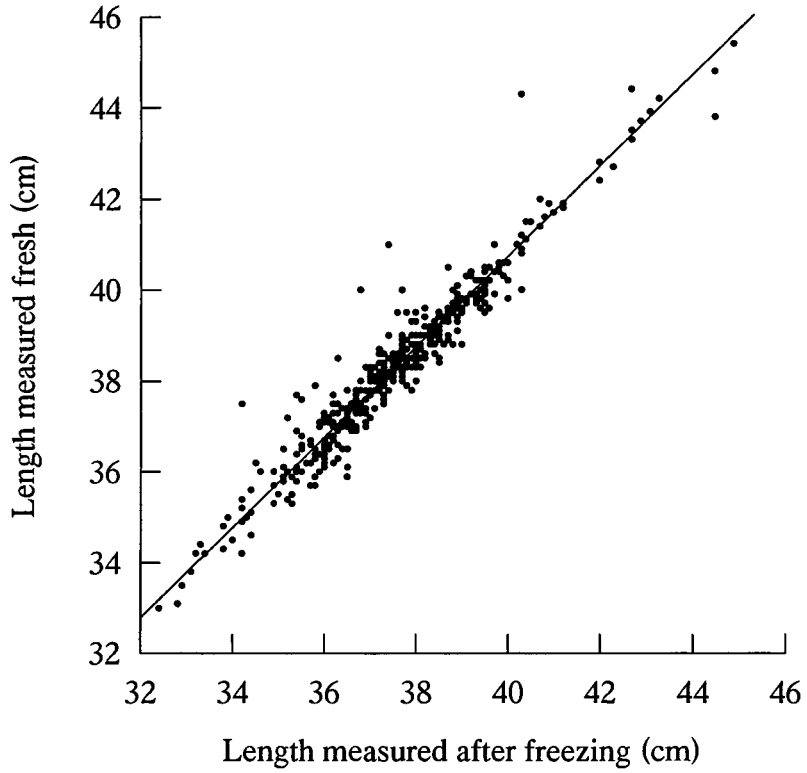

Figure 4: **Length of kahawai from Tasman Bay before and after freezing.**

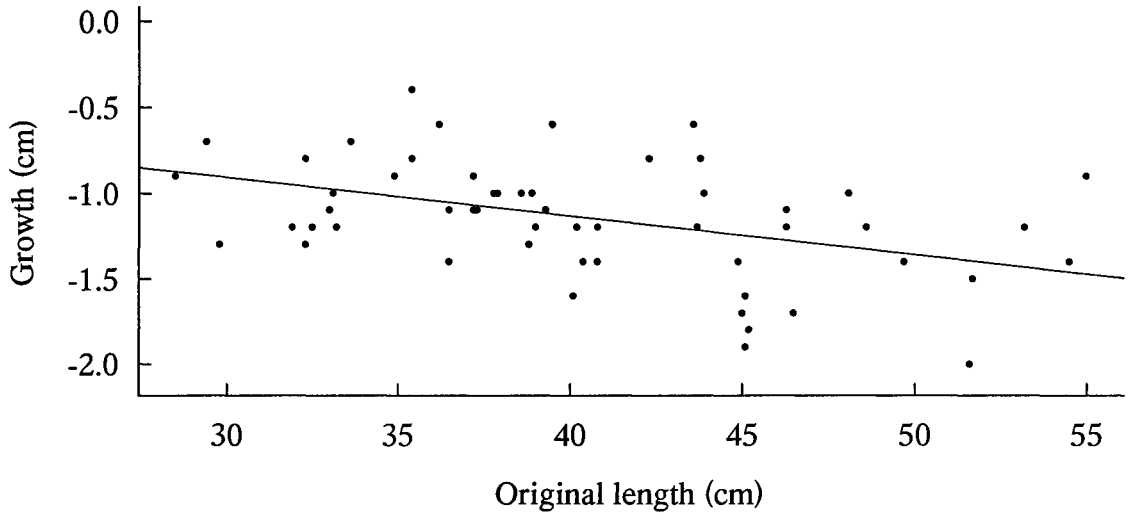

Figure 5: **Negative growth (shrinkage) due to freezing of kahawai caught around Wellington plotted against the original length at capture.**

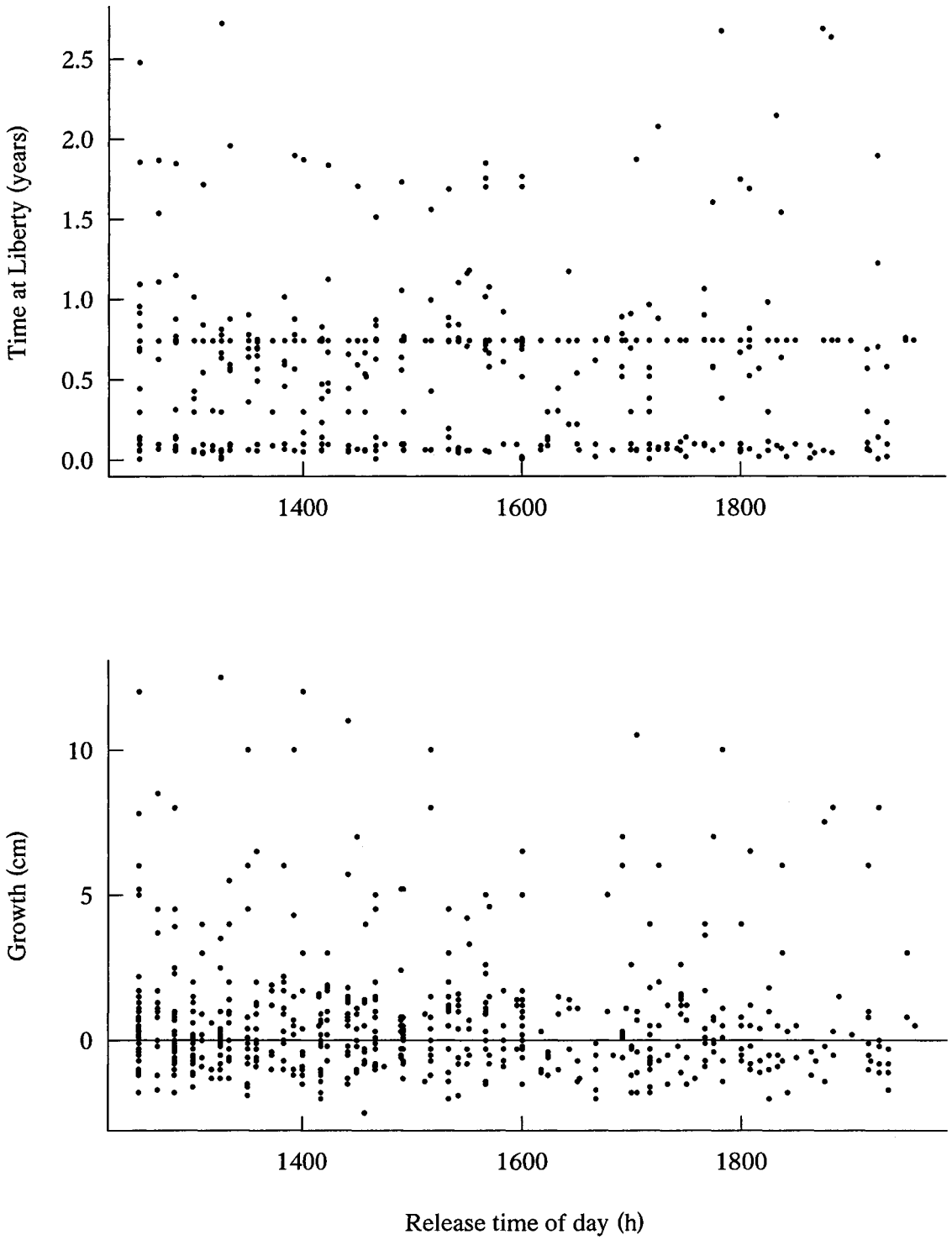

Figure 6: **Time at liberty and growth against time of tagging. Data are from the 1991 kahawai tagging experiment in Tasman Bay.**

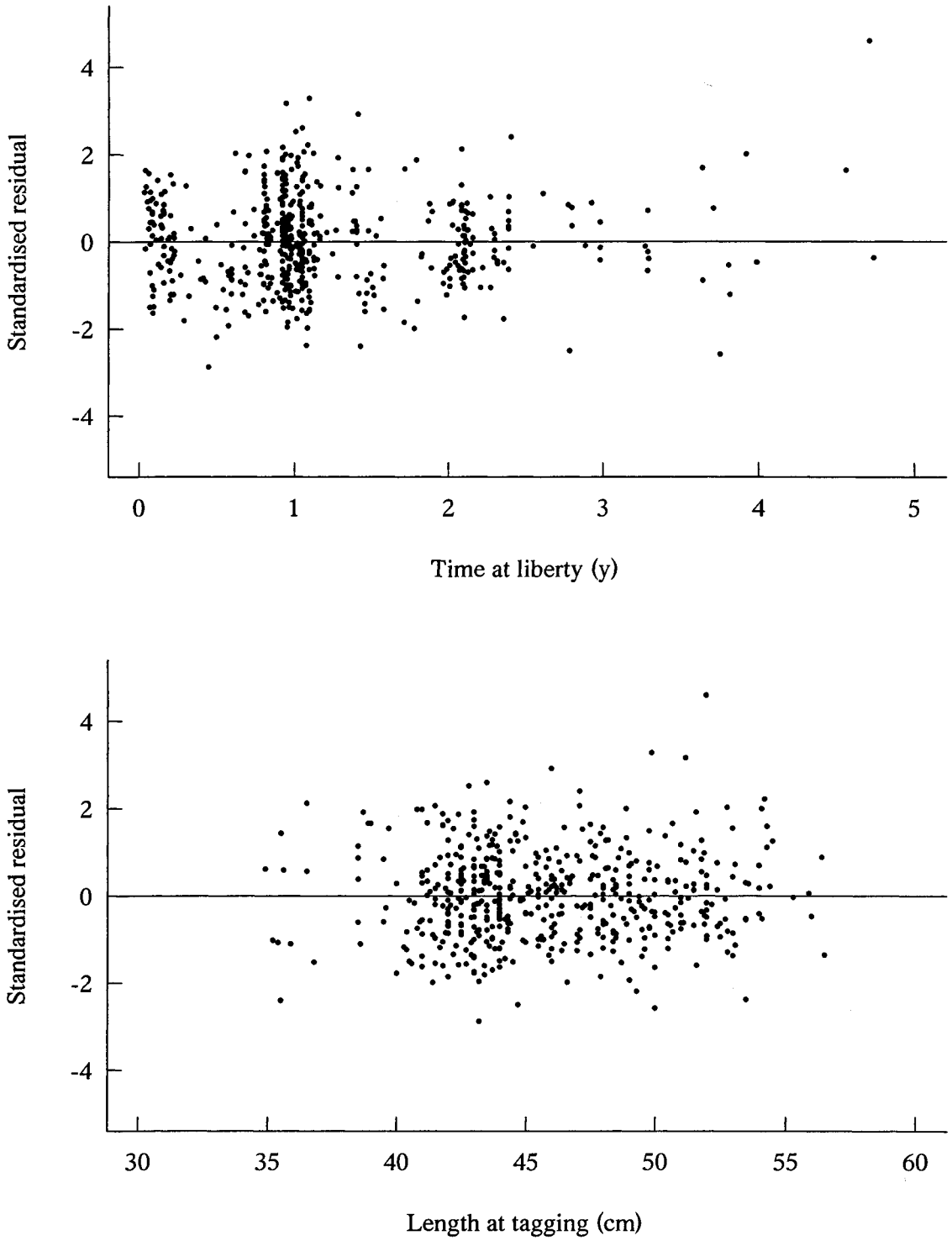

Figure 7: **Standardised residuals from GROTAG plotted against time at liberty and length at tagging, Bay of Plenty, 1991. Most outlying data points have been removed.**