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Healthier lobsters in a marine reserve: effects of fishing on disease incidence in the spiny lobster, *Jasus edwardsii*

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Abstract. Comparison of the health of spiny lobsters (*Jasus edwardsii*) within and adjacent to a New Zealand marine reserve revealed marked differences in the incidence of a handling-related bacterial infection. Lobsters outside the reserve were significantly more affected by tail fan necrosis than lobsters within the reserve, with up to 17% of the males caught outside the reserve over a 3-year period showing signs of tail fan necrosis, compared with less than 2% within the reserve. The incidence of tail fan necrosis changed abruptly at the marine reserve boundaries, strongly implying repeated handling as the causal agent. The incidence of tail fan necrosis in males increased up to the minimum legal size, consistent with a handling effect. Female lobsters, which comprise only a small proportion of the catch in this area, were comparatively unaffected by tail fan necrosis. There was no significant difference in the recapture rates of individuals tagged either with or without tail fan necrosis, but tagged individuals outside the reserve were more likely to develop tail fan necrosis than tagged individuals within the reserve. These findings have implications for both the dynamics of the lobster populations and their management, and highlight the role of marine protected areas in providing a baseline against which such effects of fishing can be assessed.

Additional keywords: marine protected areas, New Zealand.

Introduction

Diseases in marine organisms can have significant effects on not only the distribution and abundance of the affected species, but also the structure and function of the ecosystem. Disease-associated declines in abundance have been reported in a range of marine species from limpets (Carlton *et al*. 1991) to marine mammals (Castinel *et al*. 2007) and in some cases, diseases can affect multiple taxa (Cerrano *et al*. 2000). Recently, concern has been raised over apparent increases in the incidence of disease in the marine environment (Ward and Lafferty 2004) and the potential effects of climate change on aspects such as pathogen development, disease transmission and host susceptibility (Harvell *et al*. 2002).

Lobsters are susceptible to a variety of pathogens in the natural environment. For example, incidences of shell and tail disease in lobsters, both in onshore holding facilities and in wild populations, have been reported worldwide (Getchell 1989). Incidence of some diseases may be increased through the handling and stress associated with fishing or aquaculture, or is associated with degraded coastal or estuarine habitats (Sindermann 1989). Diseases in lobsters may not only cause direct mortality (Behringer *et al*. 2008), but may also weaken the animals, making them more vulnerable to other sources of mortality (Smolowitz *et al*. 1992). Disease may also result in changes in their distributional patterns, through the avoidance of diseased conspecifics (Behringer *et al*. 2006) and effects on individual movement rates (Behringer *et al*. 2008). Some diseases in lobsters may result in disfigurement, decreasing the value of the lobster and potentially affecting aspects such as the success of live-holding facilities (Musgrove *et al*. 2005).

In New Zealand waters, lobsters (*Jasus edwardsii* and *Sagmariasis verreauxi*) and paddle crabs (*Ovalipes catharus*) are susceptible to a form of shell disease manifested as erosion and blackening of the carapace, tail fan and walking legs, caused by chitinoclastic bacteria (Diggles *et al*. 2002). In Australia, this ‘tail fan necrosis’ (Musgrove *et al*. 2005) has been found to coincide with physical damage to tail fans caused during normal post-harvest handling of lobsters. Recommended management actions to reduce the prevalence of necrosis and blisters in lobsters in holding or aquaculture facilities have included improving water quality and holding conditions, and eliminating potential sources of injury (Diggles *et al*. 2002), such as preventing physical damage from conspecifics (Musgrove *et al*. 2005).

Although such diseases are more usually associated with lobsters in captivity than in the wild (Sindermann 1989), there has been a low level of incidence of tail fan necrosis in the

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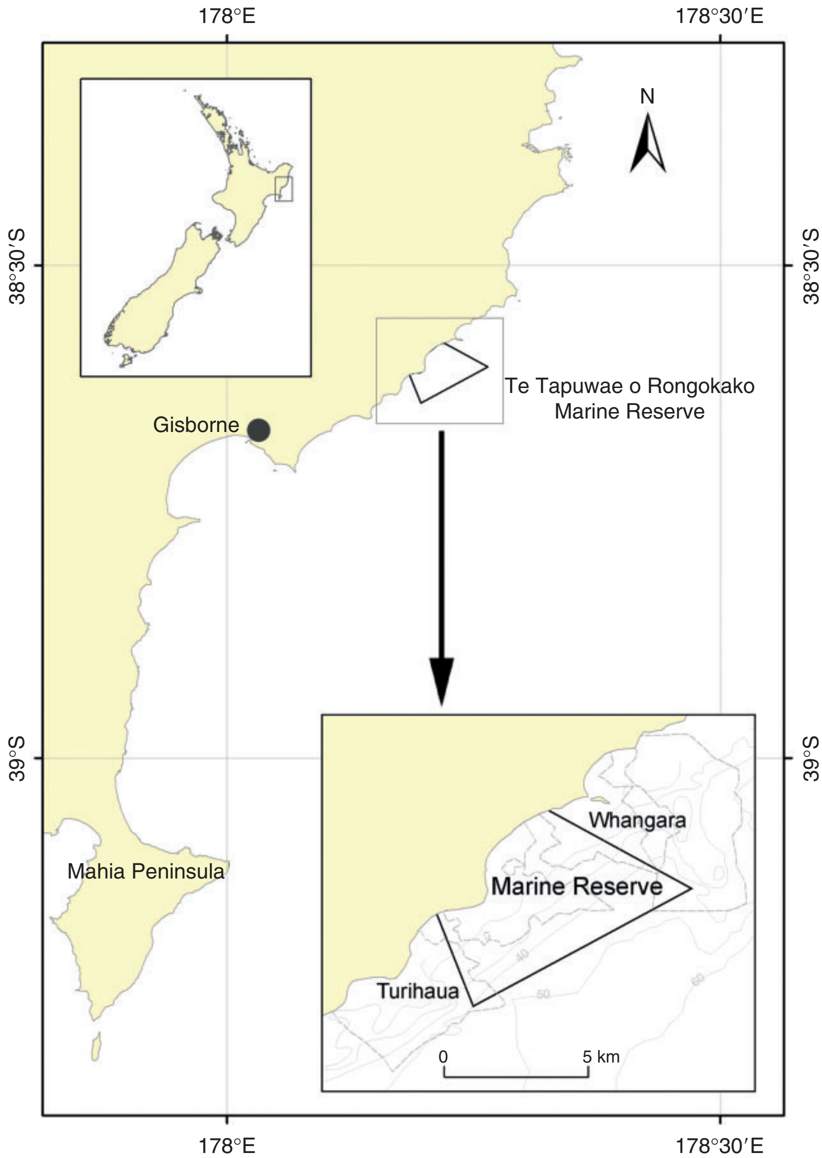

Fig. 1. Map of New Zealand showing the location of study sites on the east coast of New Zealand's North Island.

New Zealand fishery for *Jasus edwardsii* (Hutton, 1875) (Breen *et al*. 2005). In recent years, there has been a particular localised problem on the North Island's east coast, with concerns raised regarding the quality of the stock (Breen *et al*. 2005). Previously, it has not been clear whether tail fan necrosis is related to fishing or some other factor (Breen 2005). The presence of a no-take marine reserve within the affected region provided a unique opportunity for a case study on the incidence of tail fan necrosis in adjacent fished and unfished populations, and therefore to assess whether the disease is fishing related. Given previous research relating physical damage with tail fan necrosis, we hypothesised that lobsters outside the marine reserve would have a higher incidence of tail fan necrosis due to repeated capture and handling before reaching minimum legal size.

Materials and methods

Study site

This study took place on three large reef systems on the east coast of the North Island of New Zealand (Fig. 1; 178°13′E, 38°37′S). The reefs are separated by sand channels of up to ~500 m width and contain species and habitats that are representative of the wider biogeographic region. Te Tapuwae o Rongokako Marine Reserve was established in November 1999 and at 2452 ha, it is one of the largest no-take marine reserves on the mainland New Zealand coast (Department of Conservation and Ngati Konohi 1998). The boundaries of the marine reserve bisect the northernmost reef studied (Whangara Reef), completely enclose the middle reef (Pariokonohi Reef) and slice through the northern margin of the southernmost reef (Turihaua Reef).

Pot surveys

Pot surveys for lobsters on the three reefs were completed approximately every 3 months between November 2003 and November 2006. The incidence of tail fan necrosis (TFN) was recorded for every lobster sampled (except those that were dead, because in some cases parts of the dead lobster were missing), based on the presence of blistering and blackened tissue on the uropods and telson. Lobster sex and tail width were also recorded.

The location and number of pots set depended on several factors, including weather and sea conditions, the vessel used and the presence of other fishing gear. Where possible, a range of depths throughout the three reefs was sampled. The pots used were standard 52-mm mesh pots used widely in the New Zealand commercial lobster fishery.

Pots were baited with seasonally available fish and were almost exclusively set overnight. On rare occasions, adverse sea conditions prevented pots from being lifted after 24 h of soak time and so a small number of pots had 48-h soak times. Pots were generally set in groups of three to seven, depending on the extent and complexity of the reef area being sampled, and were generally no less than 100 m apart. Global positioning system (GPS) positions of each pot were recorded using a Garmin Etrex GPS (Garmin International, Olathe, KS), with an accuracy of 30 m.

Tagging

A total of 7466 lobsters was tagged (5225 within Te Tapuwae o Rongokako Marine Reserve and 2241 from outside the reserve), mostly during the pot surveys completed in November and December 2003. A small number of lobsters, from very shallow depths within Te Tapuwae o Rongokako Marine Reserve, were caught by divers and tagged on shore. Lobsters were tagged using Hallprint (Hallprint Pty Ltd, Victor Harbor, South Australia) T-bar anchor tags, inserted dorsally between the carapace and tail, either side of the centre line to avoid the intestine and as close to the tail as possible to avoid the body cavity. Insertion of the tags into this region of the muscle tissue ensured that the tags were retained during moulting. Lobsters of over 70-mm carapace length were tagged using an Avery Dennison (Avery Dennison Corporation, Pasadena, CA) Tag Fast tagging gun and TBA (standard T-bar anchor) tags. A fine anchor T-bar tagging gun and TBF (fine T-bar anchor) tags were used for lobsters with a carapace length of less than 70 mm. The tag needle was sterilised between uses. Each tag was individually numbered and had a short 'chew buffer' on its distal end. Tagged lobsters had the distal third of one pleopod clipped using scissors to enable determination of tag loss. After tagging, lobsters were immediately returned to the sea as close as possible to their capture location. Sex, tail width and the incidence of TFN were recorded for every lobster.

Data analysis

The incidence of TFN was assessed as the mean proportion of affected lobsters (divided into the two sexes) caught per 52-mm mesh pot during each survey. The proportions were arcsine-transformed to normalise the data and then weighted by the total number of males or females per pot. Analysis of variance was used to establish whether location or time had an effect on the proportion of lobsters affected by tail fan necrosis. Correlations among the incidences of tail fan necrosis at the three locations sampled were assessed using Pearson correlations (SPSS Inc., Chicago, IL). A generalised additive model (using the non-parametric smoother 's') and regression tree analysis (R Development Core Team 2007) were used to establish whether distance from the reserve boundary had a significant effect on the incidence of TFN.

The recapture rates of tagged lobsters and their incidence of TFN relative to untagged lobsters were analysed using χ^2 tests (SPSS 2006). To assess whether tagging affected the incidence of TFN, the incidence of disease in male lobsters that had been tagged at least 2 years earlier was compared with the incidence in individuals that had never been tagged, also using χ^2 tests (SPSS 2006).

To establish whether the incidence of TFN increased up to the minimum legal size, the percentages of each size class (tail widths divided into 2-mm increments) affected by TFN were compared between fished and reserve populations. Size classes with sample sizes less than 10 were excluded.

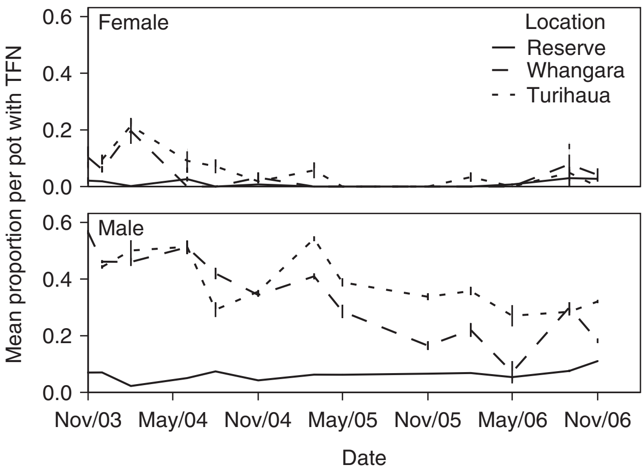

Fig. 2. Incidence of tail fan necrosis (TFN) in pot-caught (52-mm mesh) male and female lobsters, within Te Tapuwae o Rongokako Marine Reserve and at fished locations north (Whangara) and south (Turihaua) of the reserve, between November 2003 and November 2006. Proportions were arcsine-transformed and weighted by the number of lobsters of each sex per pot. Shown are the mean and standard error.

Results

Tail fan necrosis (TFN) was found to affect predominantly male lobsters (which comprised on average 90% of our catch) and particularly those within the fished areas. On the fished part of Turihaua Reef (south of the reserve), 17.1% of males and 1.9% of females caught in pots had TFN; on the fished part of Whangara Reef (north of the reserve), 16.6% of males and 2.6% of females caught in pots had TFN. Overall, 1.8% of males caught in pots within the marine reserve were affected by TFN, whereas only 0.4% of females caught within the reserve showed signs of TFN.

There was a significant positive correlation between the proportion of males affected by TFN at Turihaua and the proportion affected at Whangara ($r = 0.704$, $P = 0.011$, $n = 12$; Fig. 2).

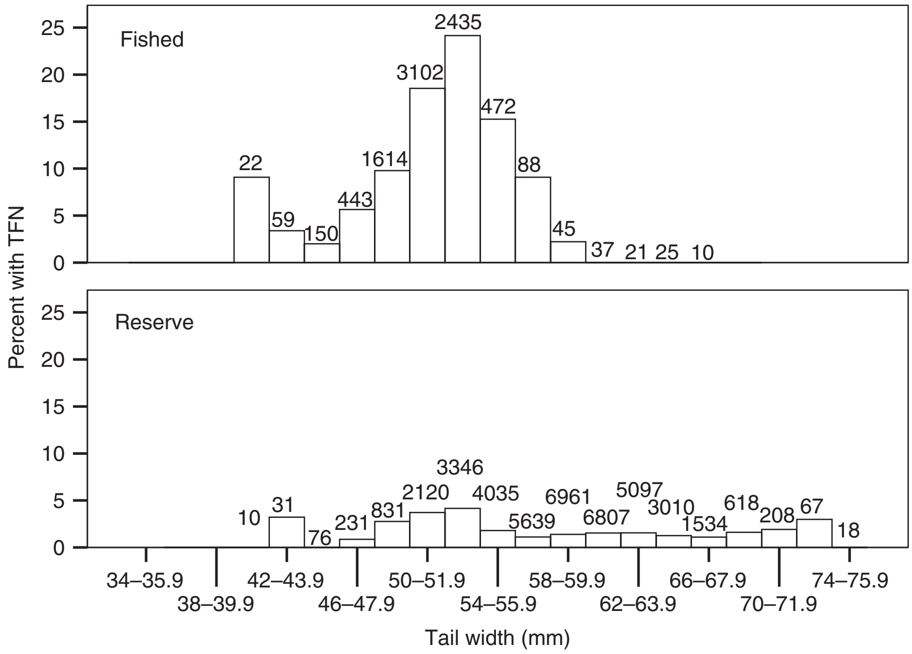

Fig. 3. Percentage of males affected by tail fan necrosis (TFN) outside and within Te Tapuwae o Rongokako Marine Reserve, by tail width. Sample sizes are shown above each bar – data are excluded where sample size was less than 10 individuals.

Survey date, location and the interaction between these factors were significant variables explaining the incidence of TFN in males ($F_{1,37} = 1120.9$, $P < 0.001$). Although the proportion of affected males outside the reserve declined over the 3-year survey period, there were clear increases in the proportions affected in early summer, following a decline in late winter.

The proportion of females affected by TFN was consistently lower over the 3-year survey period than for males. Survey date, location and the interaction between these factors were significant variables explaining the incidence of TFN ($F_{1,37} = 19$, $P < 0.001$; Fig. 2), but there was no clear pattern over time in the proportion of females affected by TFN.

Outside the reserve, males most commonly showing signs of TFN had tail widths of between 50 and 56 mm (Fig. 3), corresponding to sizes just below or just above the minimum legal size (52- or 54-mm tail width depending on season). Overall, 24.2% of all males between 52- and 53.9-mm tail width caught outside the reserve had TFN. Within the reserve, the proportion of each size class affected by TFN was low and relatively consistent across all size classes. However, there was a distinct group of individuals of between 50- and 53.9-mm tail width affected by the disease (Fig. 3).

There was no significant difference between the recapture rates of male lobsters tagged either with or without TFN (χ^2 test, $P = 0.482$ for lobsters tagged outside the reserve, $n = 1698$; $P = 0.167$ for lobsters tagged within the reserve, $n = 3783$). For those males that were tagged and recaptured outside the reserve (and for which information on necrosis incidence was recorded on both captures; $n = 140$ capture events), significantly more tagged lobsters than expected developed signs of TFN and significantly fewer than expected remained free of the disease; within the reserve, of 965 recapture events, significantly fewer than expected developed signs of TFN and significantly more than expected remained free of the disease (χ^2 test, $P < 0.001$). Male lobsters tagged in November–December 2003, and recaptured at least 2 years later were no more likely to have TFN than untagged individuals, either within or outside the marine reserve (χ^2 tests, $P = 0.086$ outside the reserve; $P = 0.176$ within the reserve).

Of the five tagged males that were recaptured four more times after being tagged, four still showed no signs of TFN (all were tagged and recaptured within the reserve) and one, which was tagged outside the reserve, remained free from necrosis on the first recapture, but subsequent recaptures were made by fishermen and necrosis was not recorded. Of 26 tagged males recaptured three times after being tagged, 20 remained free of necrosis on the third recapture; five had necrosis on the third recapture (two of these were tagged and recaptured outside the reserve, three were tagged and recaptured within the reserve) and one tagged outside the reserve was recaptured by a fisherman and disease incidence was not recorded.

Most pots set within the reserve had a low proportion of affected animals, but pots set near the reserve boundary (but still within the reserve) had a higher proportion of affected animals (Fig. 4). Fitting a generalised additive model to all data from 52-mm mesh pots showed that distance from the reserve boundary was a significant variable ($P < 0.001$) explaining disease incidence. Regression tree analysis showed that distinct and large increases in the proportion of lobsters per pot with TFN occurred within the reserve at ~130 m from the reserve boundary, then at ~1 m and 14 m outside the reserve.

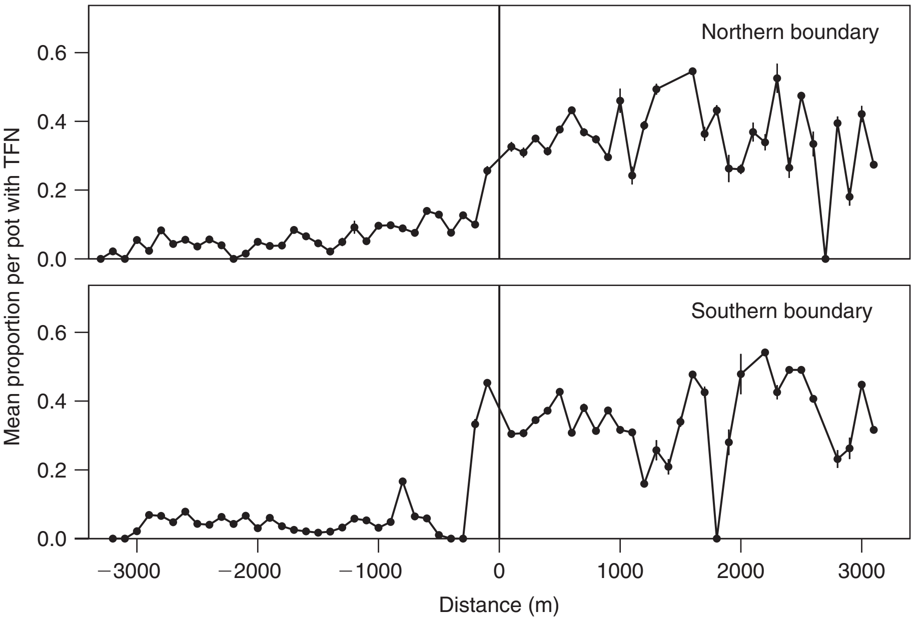

Fig. 4. Mean proportion (and standard error) of lobsters affected by tail fan necrosis (TFN) per 52-mm mesh pot, as a function of distance (in 100-m increments) alongshore from the nearest marine reserve boundary. The vertical lines indicate the boundaries of the marine reserve (points to the left of the line are within the reserve; points to the right are outside the reserve). Proportions were arcsine-transformed and weighted by the total number of lobsters per pot.

Discussion

Such high incidences of TFN have never previously been reported from other wild stocks of *Jasus edwardsii*. Te Tapuwae o Rongokako Marine Reserve provided a unique case study of the potential differences in the incidence of this disease between fished and unfished reefs within an affected region. Although we cannot completely discount the possibility that some other unknown factor explains the observed results, the marked difference in disease incidence between the adjacent fished and unfished populations and between male and female lobsters, along with the gradients in incidence across the boundaries of the marine reserve, strongly suggest that the effects of fishing explain our results.

More lobsters tagged and recaptured outside the reserve developed signs of TFN than expected, but fewer than expected within the reserve developed TFN. Females, which comprise only a small proportion of the catch in this area (Sullivan 2004), rarely showed signs of necrosis. In addition, the incidence of TFN in males increased up to the minimum legal size. Lobsters nearer the minimum legal size are likely to have been handled more frequently than smaller lobsters (simply because they have been in the water longer as sublegal-sized lobsters and their probability of escaping from pots through mandatory escape gaps before the pot is hauled reduces as they approach minimum legal size). Therefore, there exists a correlation between the incidence of necrosis and probable history of handling.

The incidence of TFN in male lobsters tended to decline around the time of the main moulting period in August–September, then increase again after the moult. This suggests that infected tissue is lost during the moult, but that the lobsters soon become infected again. Castro and Angell (2000) and Glenn and Pugh (2006) similarly noted a higher incidence of lobster shell disease in pre-ecdysis than in post-ecdysis lobsters.

A disproportionately high number of sublegal-sized lobsters within the reserve were recorded to have TFN, which may be the result of small lobsters moving into the reserve from the surrounding fishery (Freeman 2008). Lobsters within the reserve but near the boundary had a higher incidence of necrosis, suggesting some cross-boundary movement. Analysis of the overall proportion of lobsters within the reserve with TFN will have been affected by the movement of animals into the reserve.

Our sampling method (potting) means that there are issues relating to catchability (Miller 1990). In the present study, the highest catches of lobsters were immediately after the male moulting period, which also coincided with the lowest necrosis incidence. This could have resulted in an underestimation of the incidence of TFN. Conversely, the presence of larger lobsters in the marine reserve, which tend to be more catchable (Miller 1989) and which may show signs of necrosis for longer periods due to a reduced moult frequency (Castro and Angell 2000), may have led to an overestimation of TFN in lobsters within the reserve. In contrast to the finding for Caribbean spiny lobsters (*Panulirus argus*) infected with the PaV1 virus (Behringer *et al*. 2008), the recapture rate of *Jasus edwardsii* affected by TFN was no different than the rate for unaffected lobsters. However, as lobsters affected by TFN are not readily marketable and tend not to be landed in the fishery, our estimates of the recapture rate of tagged affected animals may be inflated, as these individuals would remain in the population for longer than unaffected individuals. For the same reason, our estimates of the prevalence of the disease in legal-sized animals in the fished population may be inflated. Too few legal-sized individuals tagged and released outside the reserve were recaptured to assess this possibility.

It has previously been suggested that handling and holding of spiny lobsters (*Jasus edwardsii*), in association with elevated water temperature, could predispose them to infection of damaged tissue by bacteria (Reuter *et al*. 1999). Water temperature data are not available at sufficient resolution to determine whether this could partially explain the temporal or spatial patterns in the incidence of TFN within our study area. However, the overall reduction in TFN incidence outside the marine reserve coincided with a significant reduction in total allowable commercial catch (imposed to ensure sustainability of the stock) and with a significant reduction in commercial catch (National Rock Lobster Management Group 2007). It also coincided with voluntary reductions in fishing effort by individual fishermen (pers. obs.). This further suggests that fishing effort is correlated with the incidence of TFN and suggests that the recent changes in stock management have been successful. As there was no significant change in necrosis incidence within the marine reserve over the study period, the sampling effort involved in researching within the reserve appeared to have had no detectable effect on the incidence of necrosis. Similarly, tagging had no detectable effect on the incidence of TFN in these individuals. Higher spatial resolution in fisheries catch and effort data within the affected region would be beneficial for further describing the patterns of TFN and monitoring the implementation of possible management strategies.

Acknowledgements

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