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A modelled cost-benefit analysis of hybrid PIT and conventional tagging scenarios

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Abstract Tag recovery rate is an important parameter for estimating exploitation and natural mortality in fished populations. Passive integrated transponder (PIT) technology can record 100% of PIT tagged animals passing within the detection limit of a PIT tag scanner. However PIT tags and PIT tag scanners are expensive compared with conventional visual tags and PIT tags are not detectable without scanners. We used simulation to evaluate the hybrid PIT tag which has the PIT tag incorporated into a conventional tag allowing both electronic detection capability by a scanner and visual detection by fishers. Simulated estimates of the precision and accuracy of exploitation and natural death rates for two lobster fishery management regimes: a 7-month season for both sexes and a fishery with a 10- and 6-month season for males and females, respectively, were used to determine the benefit of PIT tags. For a project budget of AU$200,000, hybrid PIT tags and 10% of the fleet being equipped with scanners produced more precise and accurate estimates of exploitation rate and natural death rate until tag reporting rate by fishers exceeds 40% for the two-gender management regime and 90% for the 7-month combined sex regime. Increasing the number of scanners to 20% of the fleet resulted in fewer hybrid PIT tags being inserted for the same cost and did not improve the precision or accuracy of estimates. Increasing the number of lobsters tagged by tagging during a higher catch rate period improved the precision of exploitation and natural death rate estimates at lower tag reporting rates for the conventional tag scenario, but did not alter the tag reporting rate required to make conventional tagging more beneficial than hybrid PIT tagging. Increased tag reporting rate by the 90% of the fleet that were not equipped with scanners had no significant impact on the precision or accuracy of estimates for either management regime.

Keywords hybrid PIT tags; multi-year tagging study; rock lobster; simulation

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INTRODUCTION

For many years, tagging studies have been conducted in fisheries research to obtain growth, movement, and mortality information (Schwarz & Seber 1999). With the development of multi-year tagging models (Brownie et al. 1985), there has been increased interest in using these models to estimate fishing (F) and natural mortality (M) (Hearn et al. 1998; Hoenig et al. 1998; Frusher & Hoenig 2001a). A key parameter in these studies is the tag recovery rate parameter (λ) that is often low owing to inconsistent reporting by fishers (Hearn et al. 1999). It has been shown that doubling the tag recovery rate gives more accurate and precise estimates of fishing and natural mortality than doubling the number of tags released (Frusher & Hoenig 2001b). Previous studies have used high reward tags, tag seeding, port surveys, or observers to better estimate tag recovery rate (Green et al. 1983; Pollock et al. 1991, 2001; Hearn et al. 1999). All of these methods have limitations with model assumptions or the practicality of implementation. High reward tag programmes assume that all recaptured tags are reported. The implementation of tag seeding methods is not always practical. And, finally, port survey and observer programmes require that fishers do not conceal tagged animals from researchers.

An alternative approach to increasing tag recovery rate that has received limited attention is to supplement or replace traditional tags in mark recapture studies with passive integrated transponder (PIT) tags and the associated scanners (Pengilly & Watson 1994; Gibbons & Andrews 2004). A PIT tag is an electronic microchip encased in biocompatible glass or plastic c. 10 mm long and 2 mm in diameter. Tags are read with the use of a scanner that generates a magnetic field, activating the tag that then transmits its number (Gibbons & Andrews 2004). PIT tags have been used in a range of fisheries in the past decade including for estimation of survival in migrant salmonid smolts (Skalski et al. 1998), investigating the effects of tagging on growth, moulting and survival of freshwater crayfish (Bubb et al. 2002), and to investigate the population dynamics in a rare species of percid (Labonne & Gaudin 2005). A number of detection devices are in use including scanners in conveyor belts (Pengilly & Watson 1994) and hand-held devices (Bubb et al. 2002).

If scanners are appropriately placed in the fishing operation so that each animal has to pass within the detection range, then it is possible to have 100% PIT tag reporting rate. A disadvantage of PIT tag technology is the increased cost when compared with conventional tags. A PIT tag is six times more expensive than a conventional T-bar tag and also requires the use of tag scanners costing several thousand dollars each (S. Frusher unpubl. data). In designing a tagging study, however, it is necessary to consider all the costs associated with the study, in particular the vessel and labour costs used to conduct the study. In this study we used simulation to investigate the cost benefit of using a hybrid PIT tag (Frusher et al. 2008) compared with a conventional tag study in spiny lobster fisheries in Australia.

METHODS

To determine the benefits of PIT tags we compared individually numbered conventional T-bar tags (Hallprint Pty. Ltd, Australia) with recently developed hybrid PIT tags (Hallprint Pty. Ltd, Australia) that incorporate the PIT tag into the conventional T-bar tag (Frusher et al. 2008, this issue). Conventional tags rely on returns from fishers, whereas hybrid PIT tags are automatically recorded by vessels with a scanner and also allow for the tag to be reported by fishers that do not have a tag scanner onboard.

We evaluated the performance of the conventional and hybrid PIT tags by simulating two fishery management regimes based on Australian lobster fisheries. The Western Australian and South Australian fisheries have a 7-month season for both sexes and the Victorian and Tasmanian fisheries have 6- and 10-month seasons for females and males, respectively. The Western Australian fishery targets western rock lobster *Panulirus cygnus* and is managed with effort controls (Srisurichan et al. 2005). The South Australian, Victorian and Tasmanian fisheries target southern rock lobster *Jasus edwardsii* and are managed with a combination of effort controls and a total allowable catch (Ford 2001; Hobday & Punt 2001; McGarvey & Gaertner 1999). In all four fisheries, lobsters are harvested with the use of baited traps that are deployed from licensed fishing vessels (Ford 2001; Hobday & Punt 2001; McGarvey & Gaertner 1999; Srisurichan et al. 2005). The dimensions of the fishing traps are standardised within each fishery although they vary slightly between the fisheries. The two different fishery management regimes used in the simulation were: (1) a season length of 7 months with both sexes open to fishing (7-month management regime) and; (2) a female season of 6 months and a male season of 10 months with fishing for both seasons starting at the same time (two-gender management regime). Catch rates and fleet size were based on a region of the Tasmanian rock lobster fishery. Mortality was parameterised as the actual mortality, the proportion of the stock that dies during the year (Ricker 1975). We used a high fishing exploitation rate (u = 0.6) and low expectation of natural death (v = 0.1), consistent with regions of the Tasmanian lobster fishery (S. Frusher unpubl. data). The number of vessels in the fishing fleet was set at 120. Simulated tag releases were conducted during the intermoult period when tag induced mortality is low, less than 10% (S. Frusher unpubl. data). Catch rates averaged 1.3 legal sized lobsters per trap lift with vessels fishing 50 traps per day. Although catch rates are highest at the opening of the fishing season in November associated with the male post-moult, tagging immediately post-moult is associated with elevated levels of tag induced mortality (S. Frusher unpubl. data).

The model

Lucas (1975) introduced a survival based model for the estimating of fishing and natural mortality from fisheries tagging experiments incorporating effort data, assuming perfect tag recovery. Burch (2002) extended the Lucas model to allow for imperfect recovery rates and multiple fleets. The Lucas (1975) approach applies standard survival analysis techniques to individual tags. Because each tag contributes individually to the likelihood, it was straightforward to include the different sections of the fishing fleet and the different tag types, conventional and hybrid PIT, as covariates in the model.

We compared three general scenarios: (1) releasing only conventional tags; (2) releasing only hybrid PIT tags and equipping 10% of the fleet with scanners; (3) releasing only hybrid PIT tags and equipping 20% of the fleet with scanners.

Although there are a variety of methods for comparing costs between different scenarios, we used a fixed budget of AU$200,000 over 3 years as a constraint to determine survey time (vessel and labour costs) and tag numbers. Half of the tags were released over each of 2 years and returns were collected for a further year. We assumed a catch rate of 1.3 legal sized lobsters per trap lift during the intermoult period. Therefore, a vessel setting 50 traps per day would be able to tag and release 65 lobsters each day.

We used the following costs, based on estimates for the Tasmanian rock lobster fishery, all of which are in Australian dollars. The daily hire cost of a fishing vessel to undertake tagging, including the skipper and deckhand was $3000. To place a researcher onboard the tagging vessel was $300 per day. Conventional T-bar tags cost $0.80 whereas hybrid PIT tags cost $5 each. The cost of a tag scanner can vary with complexity and robustness of the design and where it is fitted on the vessel; in this study, we assumed a cost of $3500 with an annual maintenance cost of $350 per unit, the total cost over 3 years was $4550 per unit.

On a fixed budget of AU$200,000, scenario 1 allowed for 60 days of tagging releasing 3900 conventional tags, scenario 2 allowed for 2600 hybrid PIT tags with 12 vessels (10% of the fleet) fitted with scanners, and scenario 3 had 24 vessels fitted with scanners and 1560 hybrid PIT tags released. These scenarios were evaluated for each of the two different fishery management regimes.

Simulation

In Tasmania, the rock lobster fishery starts after the male moult (Ziegler et al. 2003). To simulate tagging during the intermoult period, we generated tag releases 3 months into the fishing season. Half of the available tags were released in the first year and the other half one year later. The released tags were exposed to an initial tag-induced mortality rate of 10%, consistent with mortality observed in southern rock lobster (*J. edwardsii*) when tagging during intermoult (S. Frusher unpubl. data). The tags were then exposed to fishing exploitation and natural death rates of $u = 0.6$ and $v = 0.1$, respectively using the model developed by Burch (2002) with a daily time step. Exploitation rate (u) was proportioned evenly over the fishing season and v proportioned evenly over the year. A constant rate of fishing generated tag returns from the model based on the tag recovery rate (λ) of the fishing fleet. For the portion of the fleet equipped with PIT scanners we set $\lambda = 1$, that is, all tags that were recaptured by vessels equipped with PIT scanners were assumed to be reported. For vessels without PIT scanners, we simulated λ between 5% and 99%. We ran 1000 simulations for each tagging scenario and fishery management regime generating release and recapture data that we then used to estimate u and v. To simplify the modelling process, we assumed that catchability was constant over the season and fishing and natural mortality were constant over the study. Although it is unlikely that these parameters were constant, changes were expected to affect all tagging scenarios equally.

Tagging at the beginning of the fishing season

At the start of the fishing season, catch rates are highest as all newly recruited lobsters are available, but catch rates fall off over the season as legal sized animals are removed (S. Frusher unpubl. data). Because vessel time is a high cost, increased catch rates would result in more lobsters being tagged in fewer days. To determine the effect of increased catch rates, we started the simulations in November with a doubling of the catch rate to 2.6 legal sized lobsters per trap lift. On each day of tagging, 130 tagged lobsters were released from the 50 traps. We kept the tag-induced mortality at 10% to enable comparison, however, the higher tag-induced mortality associated with post-moult condition would result in the precision and accuracy of u and

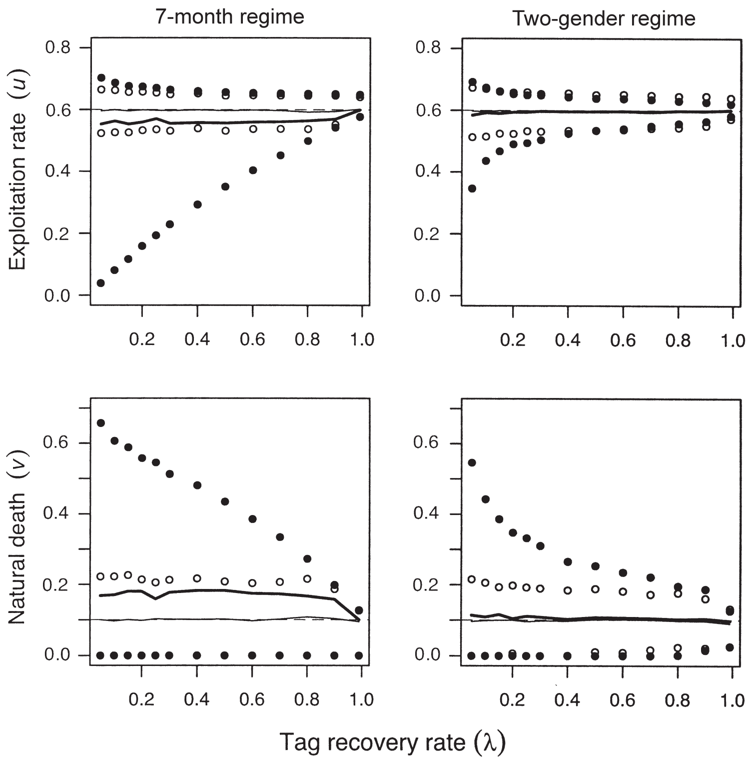

Fig. 1 Comparison of the exploitation rate and natural death rate estimates for the 7-month and two-gender management regime for increasing tag reporting rates (λ). Accuracy of the estimates (medium value) is represented by circles and precision (95% CI) by solid lines. Bold lined and closed circles represent the conventional tag scenario and thin lines and open circles the passive integrated transponder tag scenario with 10% of the fleet equipped with scanners. True values of $u = 0.6$ and $v = 0.1$ used in the simulations are represented by dashed lines.

v being less than we simulated. As more tags are released with higher catch rates, the increased cost of the additional tags necessitates a reduction in the number of days spent tagging. Scenario 1 allowed for 59 days of tagging releasing 7670 conventional tags, scenario 2 released 4810 hybrid PIT tags with 12 vessels (10% of the fleet) fitted with scanners, and scenario 3 had 24 vessels fitted with scanners and 2860 hybrid PIT tags released. These scenarios were evaluated over the two different fishery management regimes for a range of tag reporting rates from $\lambda = 0.05$ to $\lambda = 0.99$.

RESULTS

In all simulations there was negligible difference in the precision (less than 3%) and accuracy (less than 1%) of estimates of *u* and *v* between the two hybrid PIT tagging scenarios for both management regimes. The scenario with 10% of the fleet equipped with tag scanners was superior at high tag recovery rates ($\lambda > 0.8$), whereas the scenario with 20% of the fleet equipped with tag scanners performed better at low tag recovery rates ($\lambda > 0.15$). Where $0.15 < \lambda < 0.8$, we could not distinguish between the two hybrid PIT tag scenarios. For ease of presentation, the results from the scenario with 10% of the fleet covered with scanners are presented for comparison with the conventional tagging scenario.

For the 7-month management regime, the conventional tagging scenario did not exceed the hybrid PIT scenarios for precision and accuracy in estimates of *u* and *v*; only at high tag recovery rates ($\lambda > 0.8$), did it approach that of the hybrid PIT scenarios (Fig. 1). For the conventional tagging scenario, the model was unable to accurately separate the different mortalities until a tag recovery rate of 1. The estimates of *u* were biased low and the estimates of *v* were biased high. In both hybrid PIT tagging scenarios, improving the tag recovery rate of the portion of the fleet that did not have tag scanners did not improve the accuracy of estimates of *u* and *v* and did not substantially improve the precision of those estimates under this regime.

For the two-gender management regime, the conventional tags provided accurate and precise estimates of *u* equivalent to hybrid PIT tags at

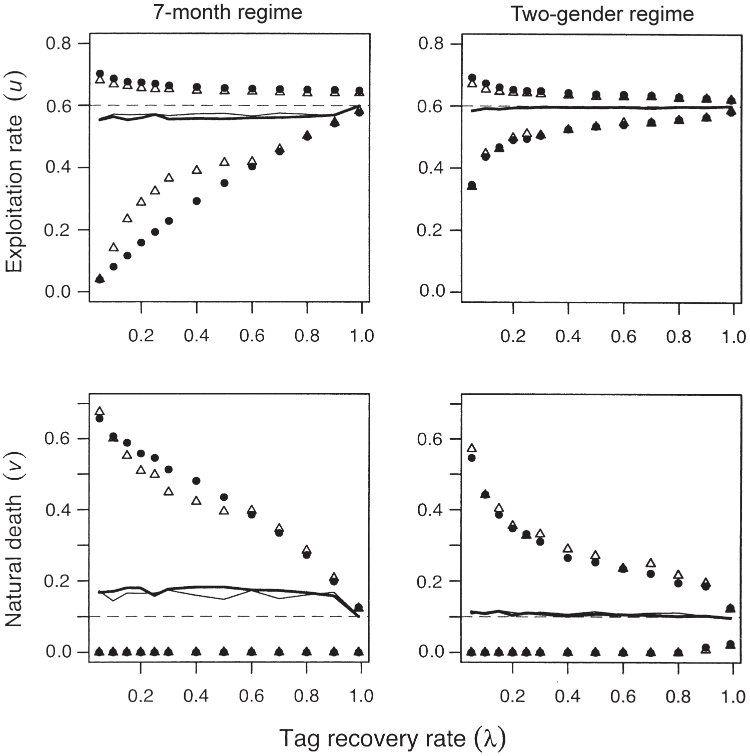

Fig. 2 Comparisons of the exploitation rate and the natural death rate estimates for the 7-month and two-gender management regime for increasing tag recovery rates (λ) for two conventional tagging scenarios. Accuracy of the estimates (medium value) is represented by circles and triangles and precision (95% CI) by solid lines. Bold lines and closed circles represent tagging at intermoult and thin lines and open triangles represent tagging at the beginning of the season when catch rates are doubled. True values of $u = 0.6$ and $v = 0.1$ used in the simulations are represented by dashed lines.

approximately $\lambda = 0.4$ and for v at $\lambda = 0.9$ (Fig. 1). In contrast to the 7-month management regime, u and v were apportioned more accurately. Similar to the 7-month management regime, the accuracy of the mortality estimates for the PIT tag scenario did not improve as the λ of the fleet improved although the precision of the mortality estimates did increase as λ increased.

When the catch rates were doubled, there was also a negligible difference between the two hybrid PIT tag scenarios in precision and accuracy of estimates of u and v under either management regime. When we compared the hybrid PIT scenarios, there was between 2% and 4% improvement in the precision of the 95% CIs of u and v for the scenarios releasing double the number of tags. There was less than 0.1% improvement in the accuracy of estimates of u and v when tags were released at the beginning of the season.

For the conventional tagging scenario under the 7-month regime, there were improvements in the precision of estimates of u and v of up to 40% for $\lambda = 0.1$ to $\lambda = 0.5$ for tagging at the beginning of the fishing season compared with tagging at intermoult (Fig. 2). There was little change in the accuracy of the estimates with u biased low and v biased high until λ reached 0.99. For the two-gender management regime under the conventional tagging scenario, there were negligible differences in estimates of u and v from tagging at the start of the season to tagging at intermoult.

Although doubling the number of tags improved the precision and accuracy of the conventional tagging scenario, the tag recovery rates at which the precision and accuracy of estimates of u and v were equivalent to the hybrid PIT tag scenarios did not change.

DISCUSSION

For equivalent cost, the PIT tag scenarios produced more accurate and precise estimates of u and v, particularly for the 7-month management regime where u was biased low and v biased high. The biased values of u and v are most likely owing to the inability of the model to differentiate between these two components of total mortality. Hoenig et al. (1998) also found it was difficult to separately estimate fishing and natural mortality with multi-year tag models unless there was substantial contrast in the estimates during fishing years. The improvement in the accuracy of u and v in the two-gender regime is likely owing to the contrast provided by the sexes being allocated to different durations of the fishing season. Under the two-gender management regime, the tag recovery rate above which the conventional scenario provides more precise estimates of u than the hybrid PIT scenario was approximately λ = 0.4.

The main cost in conventional tagging experiments is the daily vessel charter cost; under scenario 1, vessel hire accounted for 90% of the cost of the study. In comparison, vessel hire costs for the hybrid PIT tag scenarios were only 60% and 37% for scenarios 2 and 3, respectively. If the vessel hire cost can be defrayed in some way such as tagging during commercial fishing, then a conventional tagging study would benefit more than a hybrid tagging study, because it has a higher proportion of its budget associated with vessel hire. However, tag recovery rates are often less the 0.4 (Frusher & Hoenig 2001a; Hearn et al. 1999). The cost would need to be substantially reduced for a conventional tagging experiment to be on a par with a hybrid PIT experiment. For PIT tagging experiments, the cost of the tag scanners is a substantial proportion of the tagging budget; however, it is a fixed cost. In this study, we considered a 3-year experiment. If the length of the experiment was to be extended, the scanners would use a smaller proportion of any additional budget allowing either more PIT tags to be released or more scanners to be placed on vessels. Similarly, if the scanners were portable then they could be shifted to other regions of the fishery, or even other fisheries. In these instances, where the cost of the scanners is offset, it is only the maintenance costs that would need to be considered in the cost benefit analysis.

Doubling of the catch rate had negligible improvement on any of the tagging scenarios. Frusher & Hoenig (2001b) and Burch (2002) also found that increasing the number of tags is not as beneficial as increasing the tag recovery rate for conventional tagging studies.

The use of a hybrid PIT tag that incorporates the PIT tag into a conventional T-bar tag allows for tags to be reported by vessels that do not have a scanner. In addition, the reporting of the conventional part of the hybrid tag by fishers who have tag scanners onboard their vessels would allow us to estimate the tag recovery rate of the remainder of the fleet, assuming that the tag reporting rate of fishers whose vessels are equipped with receivers is the same as for those fishers whose vessels do not have receivers onboard. Although tag reporting by vessels without scanners had little impact on the precision and accuracy of u and v in this study, studies where the tagged animal can move out of the study region (e.g., migratory species) or species which have different catching sectors (e.g., recreational sector) are more likely to benefit from the hybrid tag. As the PIT tags are physically similar to conventional tags, it is likely that tag loss and tag-induced mortality are similar to estimates from previous studies based on conventional tags.

From a modelling perspective, our study using hybrid PIT tags is identical to the situation of having observers on some vessels in the fleet with the vessels that have PIT tag scanners aboard being equivalent to those with observers. Although observers may have tagged fish concealed from them, the hybrid PIT tags can be concealed from PIT scanners as fishers are able to remove the tag before placing the lobster through the scanner. The use of internal PIT tags could overcome these problems, but we did not consider their use in this study because of their high tag-induced mortality when trialled on lobster in aquaria (S. Frusher unpubl. data). For other fisheries, where tag-induced mortality is lower, or if the rate of tag-induced mortality in lobsters can be reduced, then internal PIT tags would be more difficult for fishers to conceal from PIT scanners. If internal PIT tags were to be used, then tag returns are no longer obtained from the component of the fleet without PIT scanners. However, since there was little change in the accuracy and precision of mortality estimates in the hybrid PIT scenarios as λ for the remainder of the fleet increased, it is probable these tag returns contribute little to the model. In studies where observers are used, it has been found that those vessels without an observer aboard contribute little in the modelling of tag returns (Pollock et al. 2002; Polacheck & Hearn 2003; Eveson et al. 2007).

In the last 3 years, the price of PIT tags has reduced by about 15%. If the price of PIT technology continues to decrease, the level of conventional tag recovery rate at which PIT tagging is superior to conventional tagging will increase.

We have shown under two different management regimes that PIT tags are a cost-effective method for obtaining accurate and precise estimates of exploitation and natural death rates. Only when tag reporting rate by fishers is high and consistent between fishing years are conventional tags cost-effective under these fishery management regimes. We have based this study on the characteristics of lobster fisheries in Australia, although the general methods could be applied to any fishery. As different fisheries have different costs associated, PIT tags may not necessarily be cost effective in individual situations.

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