



# Accounting for tag-induced growth retardation in spiny lobsters using censoring and modelling approaches



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## ABSTRACT

Censoring (exclusion of data based on set criteria) and modelling approaches were used to estimate and compensate for perceived growth retardation of spiny lobsters *Palinurus gilchristi* tagged with internal anchor tags. Data were available for 2862 recaptured lobsters at large for periods of 0.01 to 14.66 years in five traditional fishing areas in southern South Africa. A generalized linear model indicated that growth increments were sex and area specific, with males growing faster than females. An individual-based model that simulated the effects of growth retardation on  $K$  and  $L_{\infty}$  parameters was used to estimate the levels of censoring required to correct for increasingly severe effects. Longer growth retardation periods were easier to detect and correct for, and the undesirable effect of censoring in an unaffected population was minor. Censoring and modelling approaches provided similar estimates of growth parameters in most cases, although modelling often suffered from collinearity and apparent over-parameterization. Growth curves accounting for tag-induced retardation suggest that *P. gilchristi* grows substantially faster than previously thought, when no corrections were made. The effects of sample size on growth parameter estimates, and a reference point for management advice ( $F_{0.1}$ ), in the event of growth retardation, are shown.

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## 1. Introduction

The tagging of lobsters in the wild using internal anchor tags has long been recognized as a valuable means for studying their growth, mortality rates, movements and population structure (Wahle and Fogarty, 2006). Numbered tags are usually inserted into the abdominal muscle, so that they remain attached during moulting, when the old exoskeleton is discarded. A weakness of this method is that tagging may reduce subsequent lobster growth, although this effect appears to be species-specific (Chittleborough, 1974; Winstanley, 1976; Brown and Caputi, 1985; Cheng and Chang, 1993; Dubula et al., 2005; Frisch and Hobbs, 2011). Sub-lethal injuries caused by tag insertion (Brouwer et al., 2006; Dubula et al., 2005), air exposure and desiccation (Haupt et al., 2006; Vermeer, 1987), and interrupted foraging by displaced lobsters (Brown and Caputi, 1985) have all been implicated in reduced growth after tagging.

Tagging experiments in which growth retardation are not taken into account may bias estimates of somatic growth rates, and

affect productivity estimates in length-based fishery models, with potential economic consequences (Parsons and Eggleston, 2007). Both censoring (exclusion of data based on set criteria) and modelling approaches have been used to compensate for tag-induced bias in growth estimates. Kirkwood (1983), Hampton (1991) and Buckworth (1992) excluded animals at large for short periods from length increment analyses to reduce bias. Xiao (1994) estimated retardation simultaneously with growth parameters by adding a recovery time variable; in the model, the growth coefficient ( $K$ ) was assumed to be zero for a period  $\tau$  after tagging, whereafter normal growth resumed. Wang (1998) developed a more complex model in which  $K$  was diminished to a small value or zero after tagging ( $K_0$ ), recovering continuously thereafter to reach full  $K$ ; the model also accounted for observation-error and process-error. Both models add complexity, especially when recovery after tagging interacts with sex, size, area and season effects (Xiao, 1994; Lloyd-Jones et al., 2012).

The spiny lobster *Palinurus gilchristi* Stebbing (1900) is endemic to the continental shelf of southern South Africa, where it occurs on rocky substrata at depths of 50–200 m. It reaches sexual maturity several years after settlement, is long-lived and grows slowly (Groeneveld et al., 2013). It is targeted by a single-species commercial trap-fishery, reporting landings of 600 to 1500 t y<sup>-1</sup>. Data

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from a long-term tag-recapture programme (1978 to 2005) showed that growth rates of *P. gilchristi* depend on sex, size and location (Groeneveld, 1997), that adults moult during early summer with smaller individuals tending to moult before larger ones (Groeneveld and Branch, 2001), and that juveniles undertake long-distance migrations to upstream adult habitats (Groeneveld and Branch, 2002).

There remains some concern that data from tagging may have biased growth estimates, particularly in this deeper-water species, where sensitivity to barometric pressure changes and light exposure were presumably more acute than in shallower-water species. Increments of lobsters recaptured shortly after tagging were smaller than expected, even when excluding individuals with zero growth, that may not have moulted between tagging and recapture (Groeneveld, 1997). We compared estimates of tag-induced growth retardation in *P. gilchristi* using censoring and modelling approaches. An individual-based model was constructed to answer two questions: (a) how does retardation period influence the growth parameters of a population; and (b) how can the bias be corrected? The model was used to search and correct for possible growth retardation in the tagged *P. gilchristi* population, taking account of the effects of sex and area on growth rates (see Groeneveld, 1997). We used independent and unbiased estimates of mortality obtained within the model, and life-history theory, to constrain the range of acceptable solutions in growth parameter estimation. Further, we investigated the effects of added model complexity and uncertainty, or loss of observations through censoring, upon fishery management advice.

## 2. Materials and methods

### 2.1. Growth models with retardation

The von Bertalanffy growth model (vBgm) has been extensively used in a number of lobster taxa (Wahle and Fogarty, 2006), and is often preferred to moult process models that explicitly treat moult increment and intermoult duration, which are often not known. A slightly modified version of the vBgm was utilized to describe the expected length at age ( $L_t$ ) for individual lobsters:

$$L_t = L'_\infty (1 - e^{-K'(t-\tau)}) \quad (1)$$

where  $L'_\infty$  describes the asymptotic (mean) length at age (mm),  $K'$  the corresponding growth coefficient ( $y^{-1}$ ),  $t$  the age and  $\tau$  ( $y$ ) the possible delay or stunting caused by tagging. For simplicity the usual parameter  $t_0$  was omitted, or assumed to be zero. To describe the expected length increments ( $\Delta L$ ) at recapture from length at tagging ( $L_g$ ) and time at large ( $\Delta t$ ) the following derivations of the vBgm were utilized:

$$\Delta L = (L_\infty - L_g) \times (1 - e^{-X}) \quad (2)$$

where,

$$X = \begin{cases} K\Delta t & (2a, \text{censoring}) \\ K(\Delta t - \tau) & (2b, \text{model I}) \\ \{K_0 + \gamma(1 - e^{-\Delta t\lambda})\}\Delta t & (2c, \text{model II}) \end{cases}$$

Function (2, 2a), the traditional model suggested by Fabens (1965), was utilized after censoring of the observations. Censoring is the sequential removal of recapture observations, starting with the recaptures made right after tagging, that lead to a convergence of the growth parameters. Model I (2, 2b), proposed by Xiao (1994), performs a similar task, but attempts to estimate the recovery time  $\tau$  within the model instead. Model II (2, 2c) introduces more complexity and attempts to estimate an initial stunted growth coefficient ( $K_0$ ) and an additional growth component  $\gamma$  after full recovery, so that  $K=K_0 + \gamma$  (see Wang, 1998). In the latter

approach, full recovery time is approximated by the inverse of the third parameter, i.e.  $\lambda^{-1}$ . Although the growth parameters of Eqs. (1) and (2) have the same units, and by convention the same symbols, their meanings and values are somewhat different (Francis, 1988). The functions above were used to emulate real lobster populations with varying degrees of growth retardation and simulate the growth model fitting process in the event of retardation, as well as to analyze the growth patterns of lobsters tagged and recaptured in the field.

### 2.2. Field work

Lobsters ranging between 45 and 130 mm carapace length ( $CL \pm 0.1$  mm, measured mid-dorsally from the rostral tip to the posterior carapace edge) were selected during onboard tagging expeditions on commercial fishing vessels. A numbered plastic T-bar anchor tag (Hallprint TBA-1) was inserted into the abdominal muscle of each lobster, dorso-laterally between the posterior carapace edge and first abdominal segment, or between the first and second segments. The sex, geographic location and date of tagging were recorded, and tagged lobsters released at the sea surface. Commercial fishers were requested to return recaptured lobsters, and record the date and location of recapture. A tag-reward scheme was used as incentive to improve tag return rates. The CL increment and time at large (TAL,  $y$ ) of recaptured lobsters were used to obtain growth rate information.

Some tagging occurred in 1978 (see Pollock and Augustyn, 1982), but the bulk of tagging was undertaken between 1988 and 2005 (no tagging in 1989, 1991, 1994, 2000 and 2001). Lobsters were tagged in five traditional fishing areas (Fig. 1), spanning the known distribution range of *P. gilchristi*. Most tagging effort was concentrated at Mossel Bay–Algoa Bay, the largest and most important fishing area (Table 1). Length increment ( $\Delta L$ , mm) data were available for 2862 lobsters recaptured at all five sites, and the TAL ranged from 0.01 to 14.66 y. The mean ( $\pm$ sd) CL at tagging ( $L_g$ ) was  $75.0 \pm 9.9$  mm, and after an average TAL of  $2.0 \pm 1.98$  y the mean CL at recapture ( $L_r$ ) was  $80.0 \pm 10.0$  mm.

### 2.3. Data analyses

We performed a preliminary analysis of the growth of tagged lobsters using a generalized linear model (GLM) with Gaussian error structure and identity link. The model structure reads:

$$\text{growth} = \text{area}_5 + \text{sex}_2 + \Delta t + L_g \quad (3)$$

where growth is defined as  $\log_e(L_r/L_g)$ , the logarithm of the size increment between tagging ( $L_g$ ) and recapture ( $L_r$ ), and size is measured in mm. While the increments are expected to decrease with size and increase with time ( $\Delta t$ ) we were particularly interested in the differences between sexes and areas.

Pilot censoring experiments with field data revealed that in some sets, stable convergence in growth parameters ( $L_\infty$ ,  $K$ ) could be obtained after removal of up to a few months of data ( $\tau$  tested = 0, 2, 4, 6, 8, 10, 12 and 18 months). Following this correction we analyzed the data using the general model:

$$\Delta L = (L_{\infty[\text{sex}, \text{area}]} - L_g) (1 - e^{-K_{[\text{sex}, \text{area}]} \Delta t}) \quad (4)$$

The model was fitted to the censored observations by maximum likelihood. Analyses of residuals revealed that a Gaussian error structure was just as adequate as other more complex structures, proposed by Francis (1988). Simpler model structures were contrasted with this formulation (2), including functions that only accounted for differences between areas, sexes, or that pooled all factors. The most appropriate version was selected through comparison with the general model using the likelihood ratio test

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