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DISCREPANCY BETWEEN OTOLITH AND TAG-RECOVERY ESTIMATES OF GROWTH FOR TWO SOUTH AFRICAN SURF-ZONE TELEOST SPECIES

C. G. ATTWOOD and L. SWART**

Growth rates determined from recovered tagged galjoen *Dichistius capensis* and white steenbras *Lithognathus lithognathus* were compared to predictions from growth models based on otolith ring counts. Galjoen could not be sexed externally, but it was assumed that all fish >450 mm total length were females, which grow faster than males. Those smaller than this were assumed to include mostly males and were treated as a "male" sample. Male and female white steenbras grow equivalently. Tagged "male" (n = 322), and female galjoen (n = 34) and white steenbras (n = 14) grew more slowly than the model predictions. The discrepancy is likely attributable to the physiological effect of external tags on growth.

Fish growth parameters are commonly estimated from the counts of growth rings on hard tissue or the growth increments measured between release and recovery of tagged fish. Neither method is faultless. Estimates based on ring counts may be inaccurate because of the difficulty of interpreting rings (Neilson 1992). The growth increment of recovered fish may be biased by the effect of the tagging procedure or the tag itself on subsequent growth. In addition, measurement error is more problematic for the tag-recovery method, because it depends on the difference of two measurements, the last of which is often not executed by trained personnel.

Studies of marine fish growth rates in South Africa have been based mainly on otolith ring counts. Some surf-zone examples include galjoen *Dichistius capensis* (Bennett and Griffiths 1986), white steenbras *Lithognathus lithognathus* (Bennett 1993) and dusky kob *Argyrosomus japonicus* (Griffiths and Hecht 1995). Tag-recovery information has been used less frequently, as, for example, in the study by Govender (1999) on the growth of elf *Pomatomus saltatrix*.

It is estimated that approximately 200 000 marine fish, representing at least 200 species, have been tagged in South African waters. Since the inception of the Sedgwick's/Oceanographic Research Institute tagging programme in 1984, South African recreational anglers have been able to participate in a nationwide marine fish tag-and-release programme. In addition, there have been a few tagging projects executed by fishery scientists, which have concentrated on selected species or specific areas. There is potential to use these data more extensively for the estimation of fish growth rates, provided that the aforementioned problems with this technique are either insignificant, or can be accounted for in one way or another.

In this study, growth rates of recovered galjoen and white steenbras are compared with growth rates predicted from otolith ring counts, with the expectation of good agreement.

MATERIAL AND METHODS

Fish tagging procedure

Since 1987, more than 20 species of teleost fish have been tagged from the shore in De Hoop Marine Reserve, Southern Cape, South Africa. Fishing trips lasted for five days, and there were 12 trips a year prior to 1994, and six per year thereafter. Fish were caught from the shore, using a rod and reel with baited hooks (1/0–4/0) cast into the surf zone. The bait used included the bivalve *Donax serra*, the ascidian *Pyura stolonifera* and the polychaete worms *Arenicola loveni* and *Marphysa* sp. When a fish was landed, its total length (*TL*) was measured to the nearest millimetre. Galjoen >250 mm *TL* and white steenbras >300 mm *TL* were tagged with external plastic dart tags, 89 mm long and 1.4 mm in diameter (Hallprint, South Australia) into the musculature between the dorsal fin pterygiophores, at a distance of approximately two-thirds of the fish's length from its snout. The fish were returned to the water with as little handling as possible, and the data (species, tag code, date, total length, locality and angler) were recorded.

Each tag had inscribed on it a unique code and an address to where the tag should be returned. All fish tagging in the De Hoop Marine Reserve was done by

* Marine & Coastal Management, Private Bag X2, Rogge Bay 8012, Cape Town, South Africa. E-mail: cattwood@sfri.wcape.gov.za

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an experienced research team, initially affiliated to the University of Cape Town (prior to 1994) and thereafter, Sea Fisheries (now Marine & Coastal Management). Fish were recovered by this team, and by other recreational anglers fishing outside of the reserve. Upon recovery by the research team, the fish were measured and the relevant data recorded. Other anglers who recovered tagged fish were less diligent about the recording and submission of data. Additional information on the capture and tagging procedure can be found in Bennett and Attwood (1991) and Attwood (1998).

Statistical methods

The growth rates determined from tagged fish were compared to the growth rates determined by regression analyses of otolith ring count against body length.

The growth rate of an individual fish (G_i) was estimated from tag recovery data by subtracting the TL (mm) at release ($TL_{i\ rel}$) from the TL at recapture ($TL_{i\ rec}$) and dividing that difference by the number of days at liberty (dt). This daily growth rate was then converted to an annual rate by multiplying by 365 days:

$$G_i = 365 \frac{TL_{i\ rec} - TL_{i\ rel}}{dt} \quad . \qquad (1)$$

Only fish that had times at liberty >1 year ($dt \geq 365$) were selected for this analysis, in an attempt to reduce any bias caused by seasonal growth variations, and to reduce the effect of measurement error. A further filtering process was the omission from the analysis of all fish caught by anglers outside of the reserve, because it was found that these reportings seldom included length measurements or the length measurements were unreliable. Even among the fish tagged and released at De Hoop Marine Reserve, there were some outliers that were excluded from the analysis on the grounds that the growth rate lay more than four standard deviations from the mean. This type of error was likely to be transcription error.

The remaining G_i values were plotted against the total length of the fish midway during its time at liberty. If a Von Bertalanffy model describes galjoen growth (Bennett and Griffiths 1986), then age is linearly related to the quantity $\ell n(\ell_\infty - TL)$. Therefore, the length midway between release and recovery for galjoen was estimated as follows:

$$\overline{TL_i} = L_\infty - \exp \frac{\ell n(L_\infty - TL_{i\ rel}) + \ell n(L_\infty - TL_{i\ rec})}{2} \quad . \qquad (2)$$

White steenbras growth is approximated by a Schnute (1981) model (Bennett 1993), which is a considerably more complicated function than the Von Bertalanffy model. Fortunately, the growth curve over the size range of available tag-recovery data is close to linear, which allows the calculation of the size midway between release and recovery to be the arithmetic average of $TL_{i\ rel}$ and $TL_{i\ rec}$.

Measurement bias and error were assessed from the fish that were released and recovered on the same day by different anglers. The discrepancies between these measurements reflect measurement and transcription error, because no appreciable growth could have occurred over such a short period. The mean and standard error of these discrepancies were calculated.

The growth models for galjoen are sex-specific (Bennett and Griffiths 1986):

for male TL (mm) at age t (years),

$$TL = 472\ (1 - e^{-0.252(t - 0.694)}) \quad , \qquad (3)$$

and for female TL (mm) at age t (years),

$$TL = 677\ (1 - e^{-0.142(t - 0.282)}) \quad . \qquad (4)$$

For white steenbras (Bennett 1993), the sexes grow equivalently:

$$TL = [0.001 - 0.00087 \frac{1 - e^{0.441(t-1)}}{0.988}]^{-0.771} \quad . \qquad (5)$$

To compare the growth rates determined by tag recovery with those of the otolith-derived models, it was necessary to produce the estimates in the same units. This was done by differentiating the growth models with respect to age to give an instantaneous growth rate, and then expressing that growth rate as a function of TL. A two-step procedure was followed for each case (male galjoen, female galjoen and white steenbras):

if

$$TL = f(t) \text{ and } t = f^{-1}(TL) \quad ,$$

then

$$\frac{dTL}{dt} = f'(t) = f'(f^{-1}(TL)) \quad . \qquad (6)$$

The solved equations are:

$$\frac{dTL}{dt} = 472 \times 0.252\ (1 - \frac{TL}{472}) \text{ for male galjoen,} \qquad (7)$$

$$\frac{dTL}{dt} = 677 \times 0.142\,(1 - \frac{TL}{677}) \text{ for female galjoen,} \quad (8)$$

$$\frac{dTL}{dt} = \frac{0.441}{1.297}\,[0.001 - 0.00087\,\frac{(1 - e^{-0.441(t-1)})}{0.988}]^{-1.771}$$

for white steenbras, (9)

$$\frac{0.00087}{0.988}\,e^{-0.441(t-1)}$$

into which the following is substituted for t:

$$t = 1 - \ell n(1 + \frac{0.988(TL^{-1.297} - 0.001)}{0.00087})/0.441 \quad . \quad (10)$$

For each tag-recovery data point i, the measured growth (G_i) was compared to the expected growth rate from the appropriate model (Equations 7, 8 or 9 and 10). The comparisons were therefore between G_i and dTL/dt ($\overline{TL}$) values.

A two-tailed, paired-sample t test (Zar 1984) was used to test the null hypothesis that the growth rate determined from tag-recovery data is not different from the growth rate predicted by the models fitted to otolith data. Critical values were selected at the 95% confidence level.

Galjoen could not be sexed externally, and therefore the tag-recovery data could only be grouped into sexes on the basis of length. In Bennett and Griffith's (1986) sample of 1 148 galjoen, the largest male measured 445 mm (L_{inf} = 472 mm). It was therefore assumed that all fish >450 mm were female and that most fish <450 mm were male. The comparison of male growth rates were therefore biased in favour of higher measured growth rates by the fact that many of the fish <450 mm were faster growing females.

RESULTS

Galjoen

Between 1987 and 1997, 19 135 galjoen were tagged, of which 1 648 were recovered at least once. After filtering the tag-recovery growth data, 356 data points remained to carry out a comparison with existing growth models (Table I).

In all, 32 galjoen were released and recovered on the same day by different anglers. The difference between the total length measurements at release and recovery of those fish were used to assess the bias and error on growth estimates. The mean and standard deviation of these data were 0.16 mm and 3.2 mm respectively. As the error was considerably greater than the mean, it can be assumed that there was no bias in the estimated growth rates as a result of measuring. The true growth increment therefore lies within a 95% confidence interval of 6.4 mm on either side of the estimated rate.

The majority of the estimated growth rates lie below the corresponding value predicted by the growth-model-based otolith ring counts (Fig. 1). Over the size range 250–450 mm, the null hypothesis that the estimated growth rate and the predicted growth rate for "males" is no different was rejected at the 95% significance level. Over the size range 450–600 mm, the null hypothesis that the estimated growth rate and the predicted growth rate for females is no different was also rejected at the 95% significance level. In both cases, the growth rate estimated from tag-recovery data was slower (Table II). The 250–450 mm sample was a mix of male and female galjoen, but the fact that females are faster growing than males adds weight to the conclusion that the tag-recovery estimates are smaller.

Table I: Number of fish that were tagged and recovered and the number of data points that were rejected and used in the growth comparison

Parameter	Galjoen	White steenbras
Tagged	19 135	675
Recovered	1 648	52
Rejected because:		
recovered outside DHMR	191	9
free for< 365 days	1 093	29
outliers (> 4 *SD*)	8	0
Sample size	356	14

DHMR = De Hoop Marine Reserve

White steenbras

Between 1987 and 1997, 675 white steenbras were tagged, of which 52 were recovered at least once. After filtering the tag-recovery growth data, 14 data points remained to conduct a comparison with the existing growth model (Table I).

There were insufficient data points to estimate measurement bias and error with any confidence. Three white steenbras were caught and released within four days by different anglers on the same tagging trip. These measurement discrepancies varied between 0 and 1.6% of the body length.

All estimated growth rates lie below the corresponding

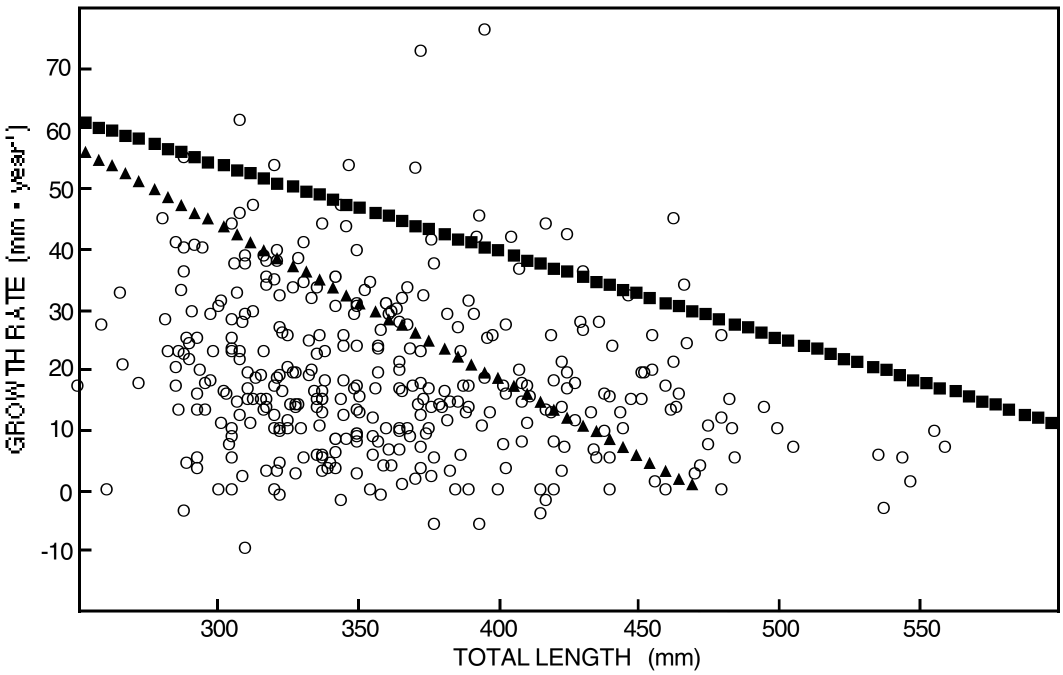

Fig. 1: The predicted growth rate of male (triangles) and female (squares) galjoen and the growth rate calculated from tag recoveries (circles)

value predicted by the growth-model-based otolith ring counts (Fig. 2). The null hypothesis that the estimated growth rate and the predicted growth rate is not different was rejected at the 95% significance level (Table II). The growth rate estimated from tag-recovery data were, on average, only 44.8% of the predicted rate (range 0–88%).

DISCUSSION

The discrepancy in growth rate observations and predictions could be a result of either the otolith ring count method underestimating age or the tagging method retarding growth, or both.

The otolith ring counts also show considerable variation, but there is no mistaking a clear trend from one age-class to the next (Bennett and Griffiths 1986, Bennett 1993). Unfortunately, those studies did not provide standard errors on the estimated growth curve parameters, and it was not possible to calculate them from the data that were presented. Marginal zone analysis indicated that only one otolith ring is deposited per year in galjoen and white steenbras, suggesting that the only source of error could be a failure to identify some rings or to separate adjacent rings. When ageing galjoen, Bennett and Griffiths (1986) counted rings on whole otoliths, which may have led to an underestimate of the true number of rings on the thicker otoliths, in which some early rings could have been obscured (Buxton and Clark 1992, Brown and Sumpton 1998). Bennett and Griffiths (1986) did section some otoliths, but noted that the small improvement in readability did not warrant the extra effort of sectioning all otoliths. When ageing white steenbras, Bennett (1993) used sectioned otoliths, which should have obviated this possible bias.

The scatter of the growth measurements and the lack of a clear trend, particularly for white steenbras, indicates that the tag-recovery method reported here for estimating growth rate is unreliable. In the case of galjoen, there were several negative growth records, which may be a combination of measurement error and very slow, or zero, growth.

The results of comparisons of growth rates estimated from ageing techniques and from tagging on other fish species are not consistent:

(i) McFarlane and Beamish (1990) found that tagged sablefish *Anaplopoma fimbria* grew slower and suffered greater mortality than

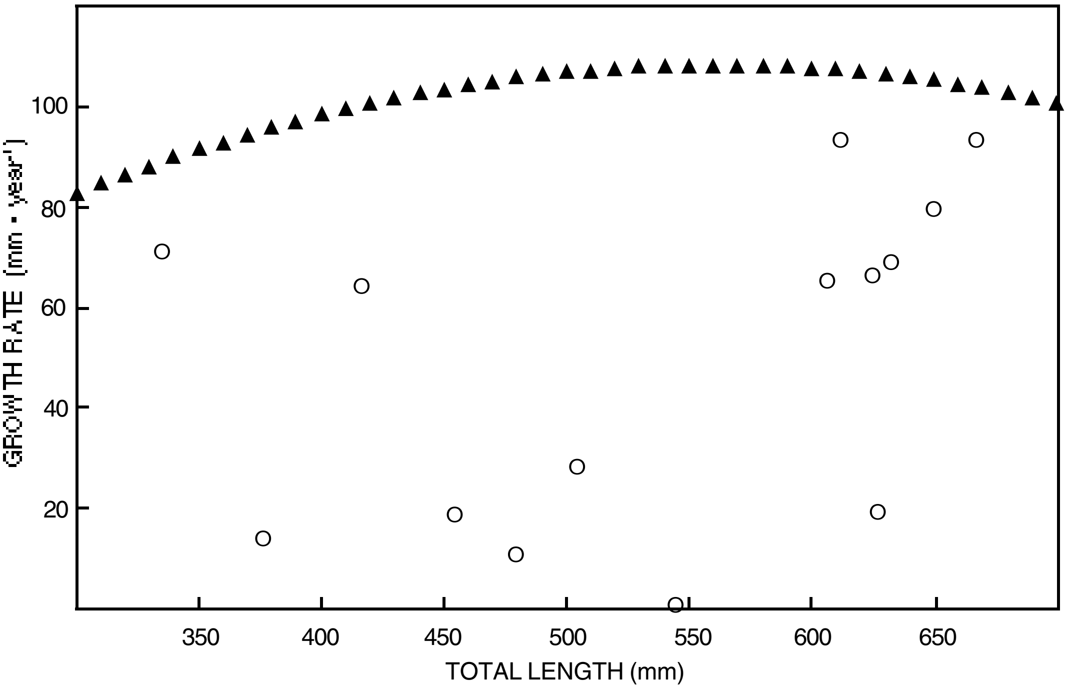

Fig. 2: The predicted growth rate of white steenbras (triangles) and the growth rate calculated from tag recoveries (circles)

untagged sablefish.

(ii) MacPherson (1992) found good agreement between the growth increments of recovered Spanish mackerel *Scomberomorus commerson* that had been tagged after capture on hook and line with those predicted from otolith ageing.

(iii) Quartararo and Kearney (1996) found that dart tags had no effect on the growth of two groups of snapper *Pagrus auratus*, one of which had been captive for eight months and the other for three weeks. Their test was based on a statistical comparison of cumulative size frequency distributions, which showed no difference between the size distributions of tagged and untagged fish at the start of the experiment and no difference at the end. This method of comparison is not as powerful as a test based on individual growth increments.

(iv) Francis and Francis (1992) found that the growth rate of net-caught rig *Mustellus lenticulatus* estimated from tag recoveries were between 2.7 and 3.3 times less than that estimated from length frequency data. The negative effect of the tag on growth was given as a likely expla-

Table II: Results of two-way, paired-sample *t* tests between growth rates estimated from tag recovery data and growth rates predicted from models based on otolith ring counts. The male galjoen sample was contaminated by females, but the female sample is almost certainly single-sex

Parameter	Male Galjoen	Female Galjoen	White steenbras
Number of fish	322	34	14
Fish size-range (mm)	258–447	451–559	335–668
Mean discrepancy (mm·year^{-1})	12.78	14.54	54.42
SE on discrepancies (mm·year^{-1})	1.09	0.78	8.91
t value	11.75	19.02	6.11
Critical *t* value 0.05 (2)	1.97	2.04	2.16

nation for the discrepancy.

(v) Ketchen (1975) noted that tagged dogfish *Squalus acanthias* often showed zero or negative growth, even when measurements were made reliably, and concluded that tag returns provided nothing more than a minimum estimate of growth rate.

(vi) Davenport and Stevens (1988) used cattle tags on sharks *Carcharhinus tilsoni* and *C. sorrah* to study growth. The recovered fish grew more slowly than the predictions based on length frequency distributions and growth band counts. A small but not insignificant fraction of the recoveries showed negative growth.

(vii) In an experiment under "semi-natural" conditions, Gruber (1982) found that tagged lemon sharks *Negaprion brevirostris* grew slower than their untagged companions.

(viii) Casey and Natanson (1992) found that the growth rates of sandbar sharks *Carcharhinus plumbeus* estimated from tag-recovery data were considerably slower than the predictions based on vertebral ring counts. The discrepancy was attributed to the unreliability of the ring counts.

(ix) Stevens (1990) found that recovered specimens of tagged *Galleorhinus galeus* had a high frequency of negative growth and that *Prionace glauca* grew slower than the growth curve prediction.

These studies, in which external tags were used, show that elasmobranch growth is negatively affected by tagging, but that not all teleost species are affected. Many authors who found a discrepancy between tag-recovery growth rates and predictions from other data sources suggest that either the capture event or the subsequent effect of the tag slows growth. All the studies that showed slower growth in tagged fish were made on specimens caught either by line or net and released into the wild. The experiment on snapper (a fish of the same family as white steenbras), which had been acclimated in tanks, did not show this result, suggesting that it may be the capture event that could retard growth or arrest it temporarily.

On the other hand, a new type of bio-compatible tag, which does not penetrate the skin, has been found not to affect growth. Farooqi and Morgan (1996) found that the growth of tagged, captive barbel *Barbus barbus* was not affected by an elastomer visible implant tag. These tags do not penetrate the skin after the initial insertion. Beukers *et al*. (1995) also found that implant tags had no affect on the growth of captive juvenile *Pomacentrus moluccensis.* In a comparison of the effects of external anchor tags and implant tags, Mourning *et al*. (1994) found that the former retarded growth and increased mortality in hatchery rainbow trout. A histopathological study by Roberts *et al*. (1973a) on the effect of external tags on Atlantic salmon *Salmo salar* showed that the severe external lesion caused by the tag does not heal in the early post-tagging period, allowing an entry point for pathogens, which leads to mortalities and presumably could affect growth. Roberts *et al.* (1973a, b) found that, over time (at least two years), the wound in Atlantic salmon does heal over, and that the external tag appears to have little effect on feeding and swimming behaviour.

In conclusion, it is likely that dart tags are not suitable for studying growth rates in galjoen and white steenbras, and caution should be exercised against their use for similar studies on other species. However, the discrepancy highlighted in this study should also bring into question the age estimates for galjoen, which were based on whole otoliths, a method that has led to underestimation in some teleost species.

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