Investigating growth information for yellowfin and bigeye tuna from the IOTTP tag-recapture data

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Executive summary

Previous growth models that were estimated for yellowfin (*Thunnus albacares*) and bigeye (*T. obesus*) tuna using tag-recapture data from the Indian Ocean Tuna Tagging Programme (IOTTP) suggested both species have a phase of slow growth as juveniles, followed by a phase of faster growth (Eveson et al. 2015; Dortel et al. 2015). One of the drawbacks of using tag-recapture data to model growth is that the age of a fish at release is unknown. These models deal with the problem by modelling the age at release as a random effect.

In 2020, the European Union and the Indian Ocean Tuna Commission (IOTC) supported a project to develop new estimates of age and growth for yellowfin and bigeye tuna in the Indian Ocean. The aim was to follow methods recently developed by Farley et al. (2017; 2020) for bigeye tuna in the Western Central Pacific Ocean (WCPO) to estimate the age and growth of yellowfin and bigeye tuna from counts of daily and annual growth zones in otoliths. Using the relationship between the daily age estimates obtained from this project and fish length, the age at release for fish in the tag-recapture data could be estimated from their release lengths. The resulting age estimates are very different than those obtained from the random effects models. Here we present these new findings and discuss potential reasons for the differences.

Introduction

A large-scale tagging programme, known as the Regional Tuna Tagging Project of the Indian Ocean (RTTP-IO), was initiated in 2005 to address uncertainties in growth, as well as other key inputs to the stock assessments, for yellowfin (YFT; *Thunnus albacares*), bigeye (BET; *T. obesus*) and skipjack (SKJ; *Katsuwonus pelamis*) tuna in the Indian Ocean. As part of the RTTP-IO, large numbers of all three species were tagged in the western Indian Ocean, primarily off Tanzania, between May 2005 and August 2007. Additional tagging also occurred in the eastern Indian Ocean as part of small-scale tagging operations, including extensive tagging of SKJ and YFT off the Maldives in 2004 and 2007-2009. In total, over 63,000 YFT, 35,000 BET, and 100,000 SKJ were tagged as part of the RTTP-IO and small-scale tagging operations, collectively known as the Indian Ocean Tuna Tagging Programme (IOTTP). Recaptures occurred subsequently in commercial fisheries operating in the Indian Ocean. At the time of data compilation for the Indian Ocean Tuna Tagging Symposium in

2012, the percent of tag returns was approximately 16% for each of the three species. Details of the tagging and recovery operations can be found in Hallier (2008) and Hallier and Fonteneau (2015).

In our investigation here, we concentrate only on the tag-recapture data from YFT and BET. For both species, the growth rates calculated from the tag-recapture data (cm/day) show a clear change/increase at ~55 cm fork length, with smaller fish growing more slowly than larger fish (Eveson et al. 2015). The magnitude of the change is larger for YFT. Daily age estimates from otoliths collected as part of the IOTTP (Sardenne et al. 2015) lent some support to this pattern, but discrepancies in age estimates between different otolith readers and large variability in the resulting length at age data made any conclusions difficult (Eveson et al. 2015).

One of the drawbacks of using tag-recapture data to model growth is that the age of a fish at release is unknown. Maximum likelihood and Bayesian approaches have been developed that deal with this by modelling the age at release as a random variable (e.g., Palmer et al., 1991; Wang et al., 1995; Laslett et al., 2002; Dortel et al. 2015). These models attempt to estimate a release age distribution that is most consistent with the release length, recapture length and time at liberty data for the growth model being assumed. For example, if a von Bertalanffy model is chosen, the assumption is that growth rates decline with age, so for fish of a given length, those with a lower growth rate will be estimated to be older than those with a higher growth rate.

Eveson et al. (2015) used tag-recapture data from the IOTTP along with otolith daily age estimates from Sardenne et al. (2015) to estimate growth models for YFT and BET. For both species, a VB log k growth curve (Laslett et al. 2002) was chosen to capture the two phases of growth. The fitted growth models suggest YFT and BET have a phase of slower growth when they are juveniles, followed by a phase of faster growth. YFT make a quick transition between growth phases, with a short period of very rapid growth immediately following the age of transition, whereas BET make a smoother, more gradual transition. Kolody (2011) suggested that differential size-selectivity between the FAD (fish aggregating device) and free-set components of the purse seine fishery could result in apparent two-stanza growth; however, the pattern held when recaptures from either component of the fishery were considered independently.

In 2020, the European Union and the Indian Ocean Tuna Commission (IOTC) supported the 'GERUNDIO' project for the "*collection and analysis of biological samples of tropical tunas, swordfish, and blue sharks to improve age, growth and reproduction data for the IOTC*". One of the objectives of the project was to develop new estimates of age and growth for yellowfin and bigeye tuna in the Indian Ocean. The aim was to follow methods recently developed by Farley et al. (2017; 2020) for bigeye tuna in the Western Central Pacific Ocean (WCPO) to estimate the age and growth of yellowfin and bigeye tuna from counts of daily and annual growth zones in otoliths. The results for YFT and BET are presented in Farley et al. (2021a) and Farley et al. (2021b) respectively. Using the relationship between fish length and the daily age estimates obtained from the GERUNDIO study, we could estimate age at release for fish in the tag-recapture data from their release lengths. The resulting age estimates are very different than those obtained from the random effects models in Eveson et al. (2015). Here we present these new findings and discuss potential reasons for the differences.

Methods and Results

In the investigations done here, we used the same tag-recapture data set used in the growth models of Eveson et al. (2015), which had been filtered based on screening criteria determined by the Secretariat of the Indian Ocean Tuna Commission (IOTC).

Yellowfin tuna

Figure 1 shows the release and recapture distributions for YFT, broken down by those released off Tanzania (N=4035) and those released elsewhere (N=301). The distribution of release lengths shows two distinct modes, one centred around 48 cm and the other around 62 cm with a separation between them at ~54 cm (Figure 2). The average growth rate for each fish over the time it was at liberty was calculated as the difference between the recapture length and the release length (in cm) divided by the time at liberty (in days). Plotting growth rate against release length shows that fish in the smaller release length mode (<54 cm) had slower growth in general than fish in the larger release length model (≥54 cm) (Figure 3). For fish with release lengths ≥54 cm, growth rates decline with length and are also slightly lower for fish at liberty for longer (Figure 3), both of which are expected if growth monotonically declines with age (like a von Bertalanffy curve). However, for fish with release length <54 cm, there are two clouds of points, one with slightly higher growth rates than the other. The cloud of fish with higher growth rates corresponds to fish that were at liberty for over a year (Figure 3), which suggests the growth of fish released when small (<54 cm) is slow for the first year after tagging, then increases if they remain at liberty for longer, resulting in a higher average growth rate. Another way of looking at these data is to plot growth rate against time at liberty (Figure 4). Fish <54 cm at release grow slowly if they were at liberty for less than a year, but the average growth rate starts to increase for fish at liberty longer to a peak around 500-600 days before declining again (as expected as fish get older) (Figure 4, top). For fish ≥54 cm at release, there is an initial period of highly variable growth between 100-200 days at liberty, with slow growth for many fish, but for fish at liberty longer than this, their growth rates follow the expected pattern of fast initial growth with a decline over time (Figure 4, bottom).

In Farley et al. (2021a), age estimates were obtained for 74 YFT otoliths selected for daily ageing. The relationship between fork length and daily age is shown in Figure 5. A non-parametric smooth was fit to these data and used to estimate the age at release of fish in the tag-recapture dataset based on their length at release. Note that age was only estimated for fish with a release length between 20-70 cm (N=4052 out of 4336), since this is the range that was used in developing the age-length relationship. The estimated release ages ranged from 0.24 to 1.21 years with a mean of 0.93 years (Figure 6, blue bars). The age at recapture could then be estimated for each fish by summing its estimated release age with the time it was at liberty. A plot of recapture length versus estimated recapture age shows that, up to a recapture age of around 2.5 years, fish released at a smaller size (<54 cm) attained a smaller length at recapture than fish of the same age released at a larger size (≥54 cm) (Figure 7). For fish that remained at liberty longer and were recaptured at older ages (>2 years), the lengths at recapture for the two release mode groups become similar. The otolith age and length data from Farley et al. (2021a) are overlaid for comparison, including both the daily age estimates and the decimal age estimates derived from annual ageing (Figure 7). These data align quite well with the recapture data for fish from the larger release length mode, particularly for fish <2 years old. Between ages 2 and 4 years, YFT from the otolith data set appear to be slightly smaller for the same age as fish from the tag-recapture data set, but since the data were collected from different regions of the Indian Ocean in different years, this could be explained by spatial or temporal differences in growth.

The recapture length versus age data in Figure 7 look very different to the data from Eveson et al. (2015), regardless of whether the Sardenne et al. (2015) otolith data from reader Team 1 or Team 2 were included in their models (Figure 8). The recapture lengths are the same, so the difference is due to the estimated recapture ages, and more specifically to the estimated release ages since in both cases recapture age is the sum of the estimated release age and the time at liberty. The release ages estimated in Eveson et al. (2015) are older and cover a wider age range than those estimated here (Figure 6). Reasons for this are discussed in the Discussion.

Bigeye tuna

Figure 9 shows the release and recapture distributions for BET, broken down by those released off Tanzania (N=2922) and those released elsewhere (N=14). As for YFT, the distribution of release lengths shows two distinct modes, centred around 48 and 62 cm with a separation between them at ~55 cm (Figure 10). Similar to YFT, fish in the smaller release length mode (<55 cm) had slower growth in general than fish in the larger release length model (≥55 cm) (Figure 11). For BET <54 cm, fish at liberty for over a year still have higher growth rates on average than those at liberty less than a year, but the difference is not as great as for YFT (Figure 11). This makes sense since the “jump” in growth rates between the smaller and larger release modes is not as great for BET as for YFT; thus, the average growth rate for fish released when small (<55 cm) but at liberty for over a year still increases, but not by as much. Again, this can be seen by plotting growth rate against time at liberty (Figure 12). For fish <55 cm, the increase in the average growth rate that occurs around a year at liberty is not as large as for YFT, and the peak occurs at around 450-500 days before declining (Figure 12, top). For BET ≥55 cm at release, growth rates are a bit more variable and slower in the initial period but not to the same extent as for YFT; rather their growth rates better follow the expected pattern of fast initial growth with a decline over time (Figure 12, bottom).

In Farley et al. (2021b), age estimates were obtained for 37 BET otoliths selected for daily ageing. The relationship between fork length and daily age is shown in Figure 13. A power curve was fit to these data and used to estimate the age at release of fish in the tag-recapture dataset based on their length at release. Age was only estimated for fish with a release length between 18-79 cm (N=2914 out of 2936), since this is the range that was used in developing the age-length relationship. The estimated release ages ranged from 0.30 to 1.64 years with a mean of 0.78 years (Figure 14, blue bars). Again, age at recapture was estimated for each fish by summing its estimated release age with the time it was at liberty. As for YFT, BET released at a smaller size (<55 cm) attained a smaller length at recapture than fish of the same age that were released at a larger size (≥55 cm), and this trend held for longer for BET (up to ~age 4) (Figure 15). For fish that were recaptured beyond age 4, the lengths at recapture for the two release mode groups became similar. The otolith age and length data from Farley et al. (2021b) are overlaid for comparison, including both the daily age estimates and the decimal age estimates derived from annual ageing (Figure 16). Similar to YFT, these data align reasonably well with the recapture data for fish from the larger release length mode, and slight differences could be explained by spatial or temporal differences in growth since the otolith data were collected from different regions of the Indian Ocean in different years.

The recapture length versus age data for BET (Figure 15)Figure 7 look very different to the data from Eveson et al. (2015) (Figure 16), as are the estimated release age distributions (Figure 14). However, compared to YFT, the release ages estimated for BET in Eveson et al. (2015) differed more depending on whether otolith data from reader Team 1 or Team 2 were included in the models. The estimates that included Team 1 data were more similar to our estimates, but still showed a wider age range; those that included Team 2 data also showed a wider age range and were much older than our estimates (Figure 16).

Discussion

The results presented here suggest quite different growth curves for YFT and BET from the tag-recapture data than those obtained in Eveson et al. (2015); this is due to very different release ages being estimated for the fish. In fitting a growth model to the data, an assumption is that all fish have the same mean length for a given age – there can be variability around the mean, but not different means for different subsets of fish. The independent release age estimates we obtained here suggest that this assumption is not being met – for both YFT and BET, fish from two different release length modes have different mean lengths at age. The only way for the growth models that estimate release age as a random effect, such as that in Eveson et al. (2015), to deal with this is to estimate the age of the fish with the larger lengths to be older. Although our estimates of release age contain some uncertainty, the relationship between fish length and otolith daily age on which they are based is quite good, and the uncertainty will be small compared to the uncertainty in age estimates obtained from the random effect growth models.

The reason for the difference in mean lengths at age for fish from the two release groups is not clear. If the fish were released in different areas or different years then the difference could be due to spatial or temporal difference in growth; however, they were almost all released off Tanzania in the same two years. For YFT, there were ~300 fish in the data set that were released elsewhere and, while the variability in the growth rates were larger for these fish, they showed a similar pattern to those released off Tanzania (Figure 4). There were almost no BET in the dataset from non-Tanzanian releases to make an informative comparison (Figure 12). One possible explanation is that tagging affected the growth of the fish, and this effect was larger and lasted longer for fish that were smaller when tagged (i.e., those in the smaller release length mode). This is consistent with our observation that fish from the smaller release length mode eventually "caught up" in length to those from the larger release length mode if they were at liberty for long enough.

Acknowledgements

The tuna tagging data analysed in this study were collected through the Indian Ocean Tuna Tagging Program (IOTTP) under the Regional Tuna Tagging Project of the Indian Ocean funded by the 9th European Development Fund (9.ACP.RSA.005/006) of the European Union, and small-scale tagging projects funded by the European Union and the Government of Japan, such as the West Sumatra Tuna Tagging Project. The GERUNDIO project is supported by financial assistance of the European Union (contract no. 2020/SEY/FIDTD/IOTC - CPA 345335). The views expressed herein can in no way be taken to reflect the official opinion of the European Union.

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Figures – yellowfin tuna

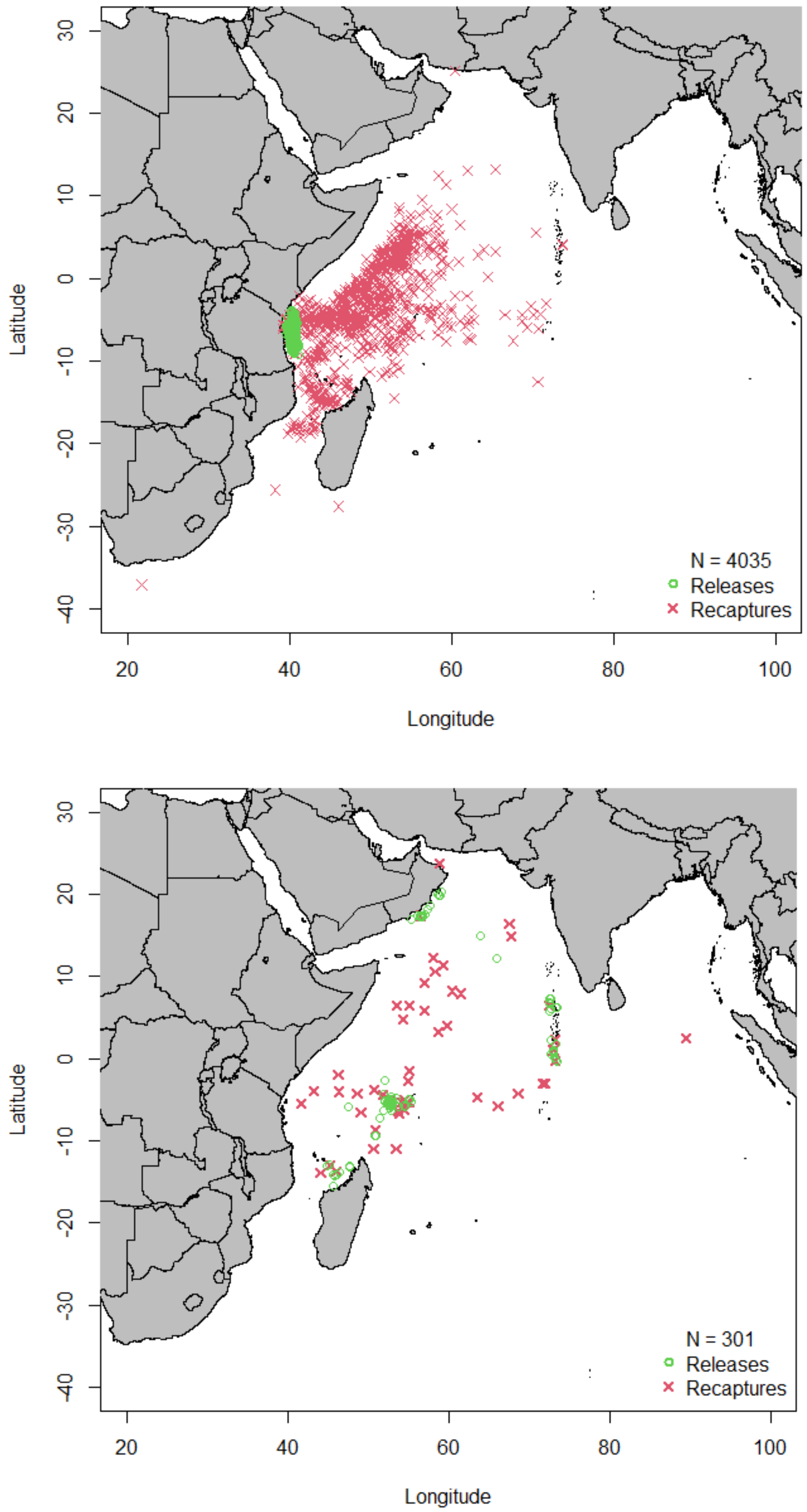


Figure 1. Map of the release and recapture locations for yellowfin tuna used in the growth analysis of Eveson et al. (2015), showing fish that were released off Tanzania (top) and released elsewhere (bottom).

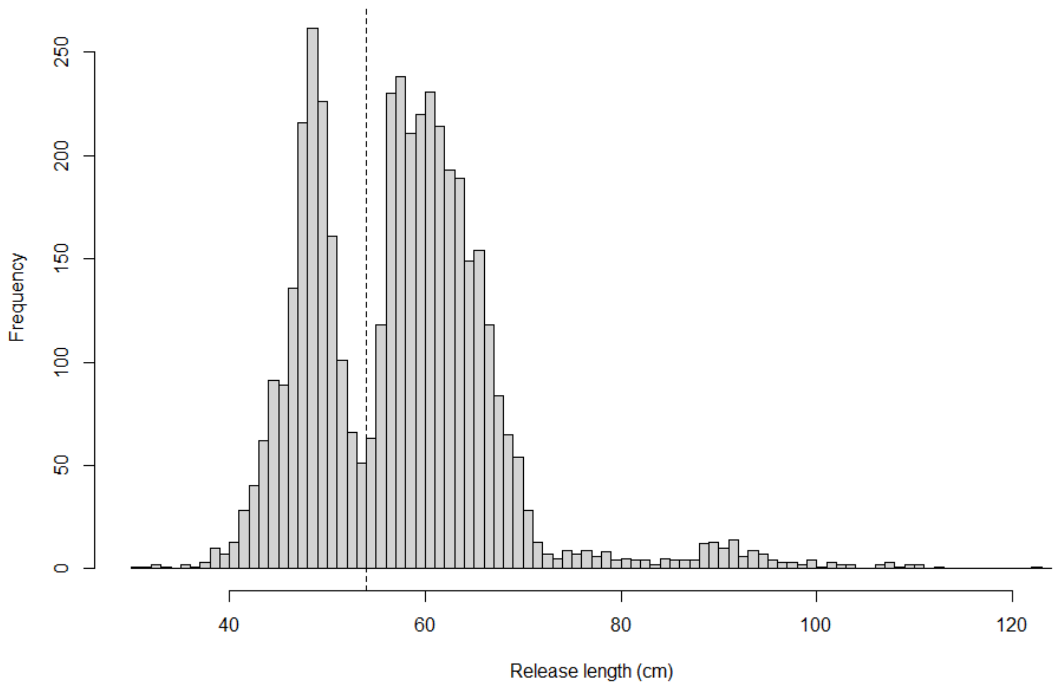


Figure 2. Release length distribution of yellowfin tuna used in the growth analysis of Eveson et al. (2015). There is a separation between modes at 54 cm (dashed vertical line).

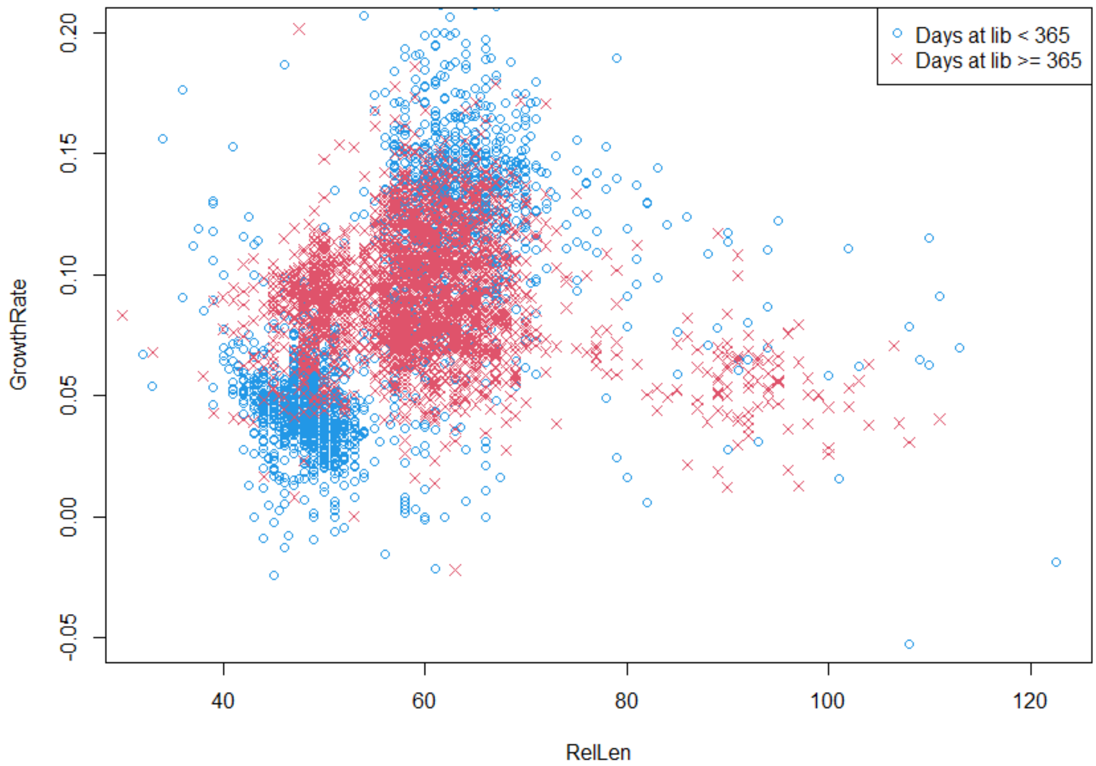
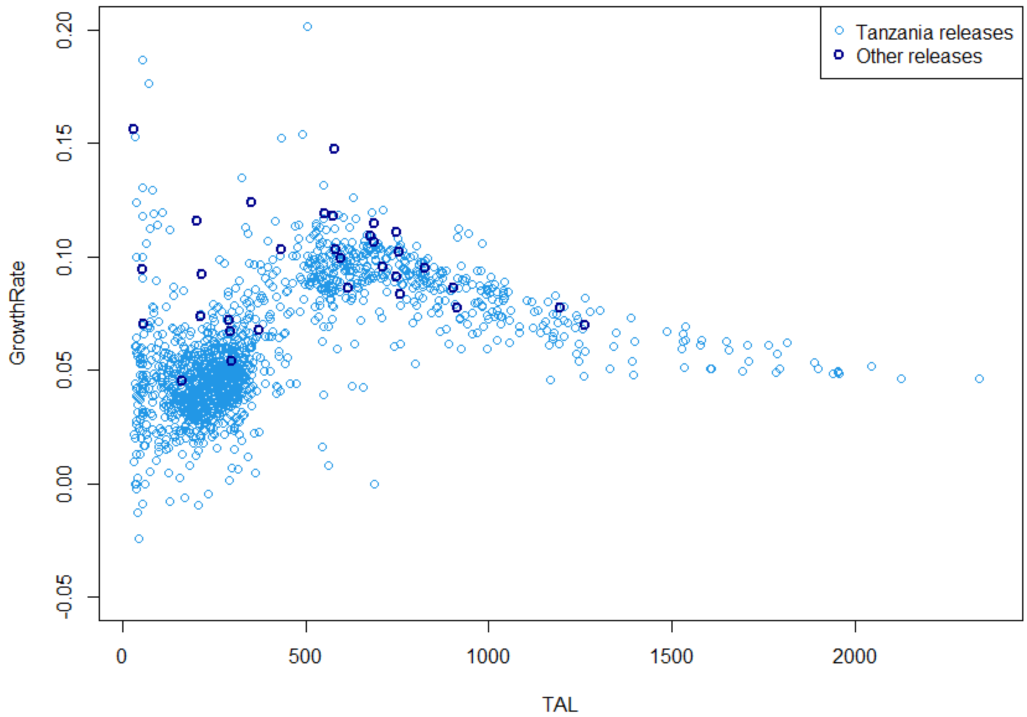


Figure 3. Growth rate (cm/day) versus release length (cm) for yellowfin tuna, broken down by time at liberty (<365 days vs ≥365 days).



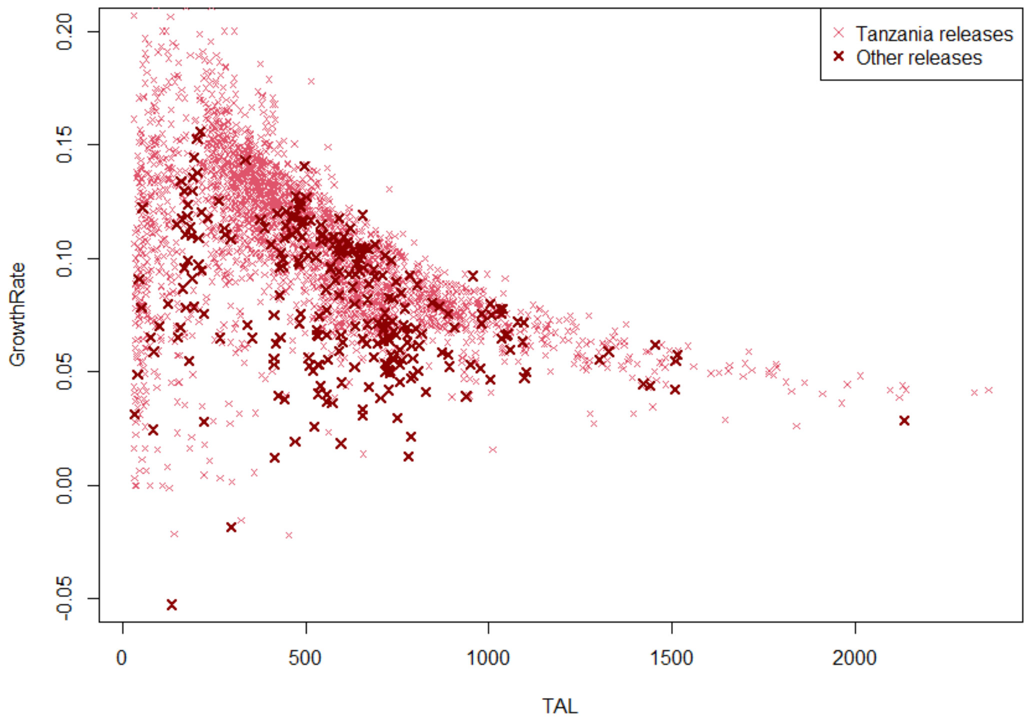


Figure 4. Growth rate (cm/day) verses time at liberty (TAL, days) for yellowfin tuna that were < 54 cm at release (top) and ≥54 cm at release (bottom). Those released in areas other than Tanzania are highlighted for comparison.

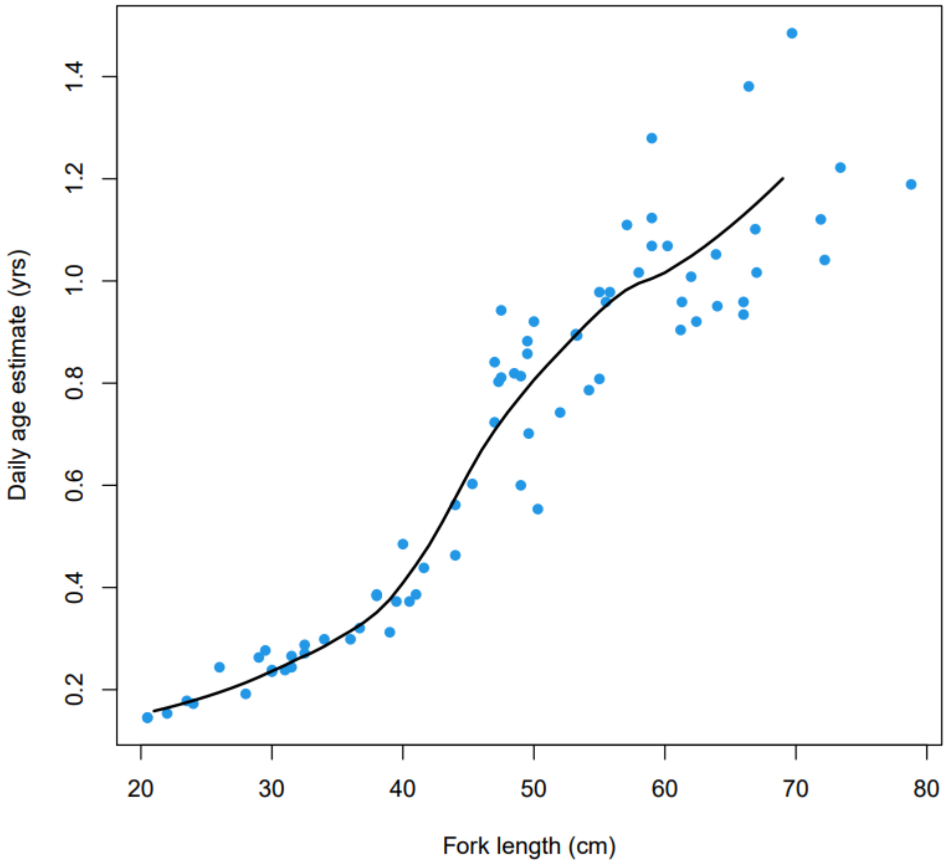


Figure 5. Fork length vs otolith daily age for yellowfin tuna, with a non-parametric smooth model fitted to the data (taken from Farley et al. 2021a). Only fish < 70 cm FL were included in the smooth since the data are too sparse and variable for larger fish to be confident in the age-length relationship.

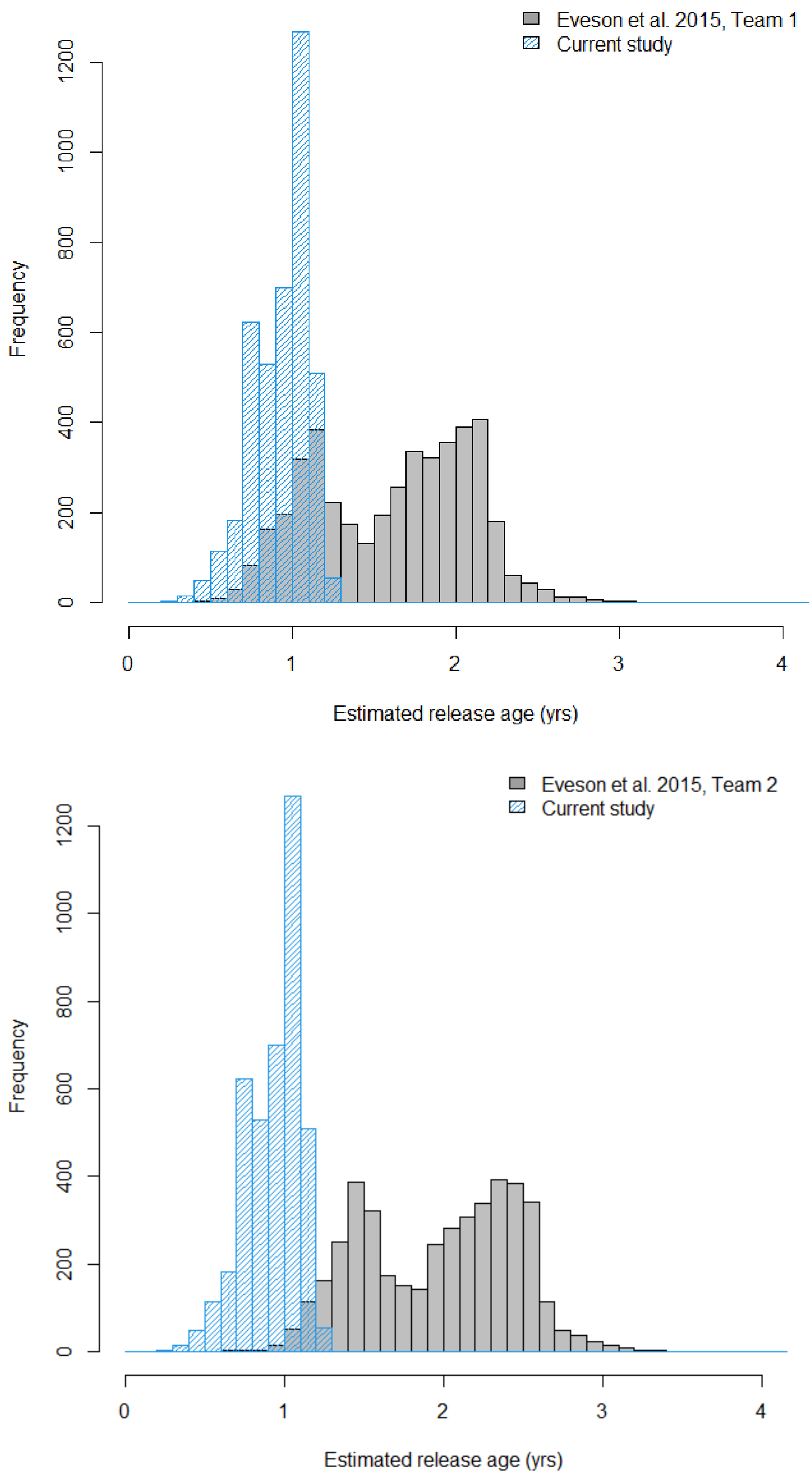


Figure 6. Histogram of release ages estimated for yellowfin tuna in the current study using the length versus daily age relationship in Figure 5 (blue bars) compared to release ages estimated from the growth model in Eveson et al. (2015) (grey bars), which included tag-recapture data and otolith data from Sardenne et al. (2015) for reader Team 1 (top) or reader Team 2 (bottom).

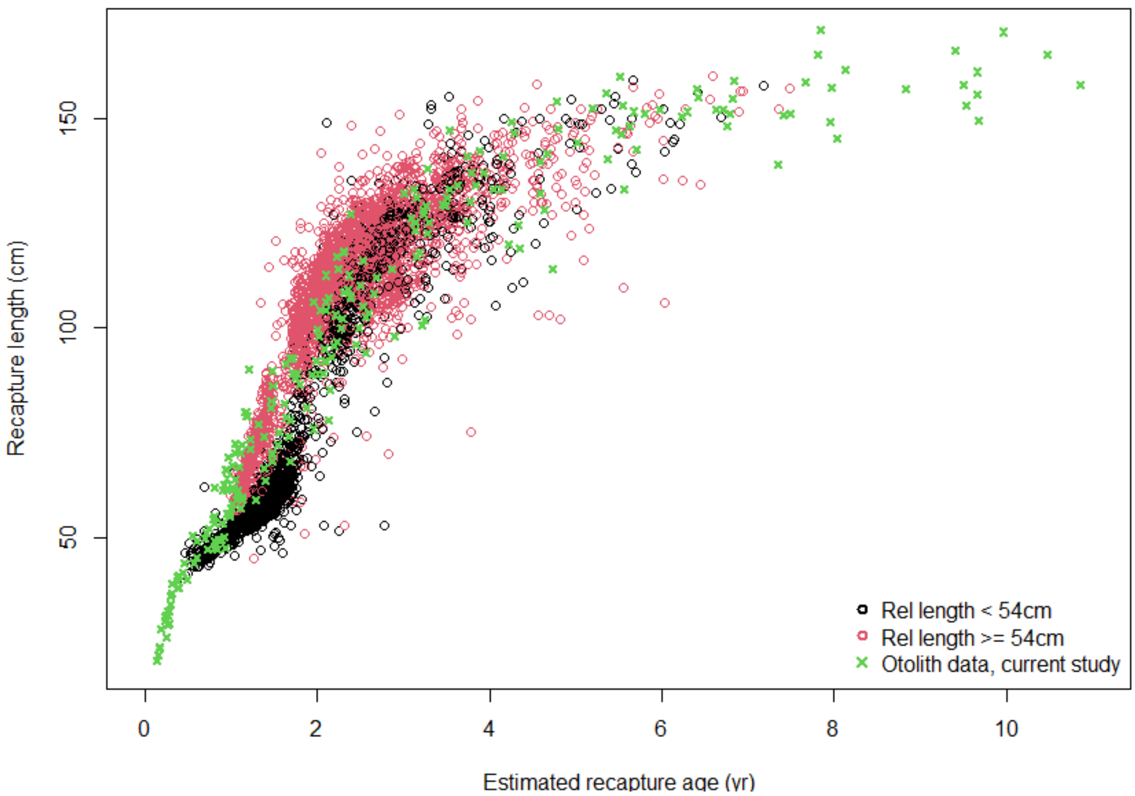
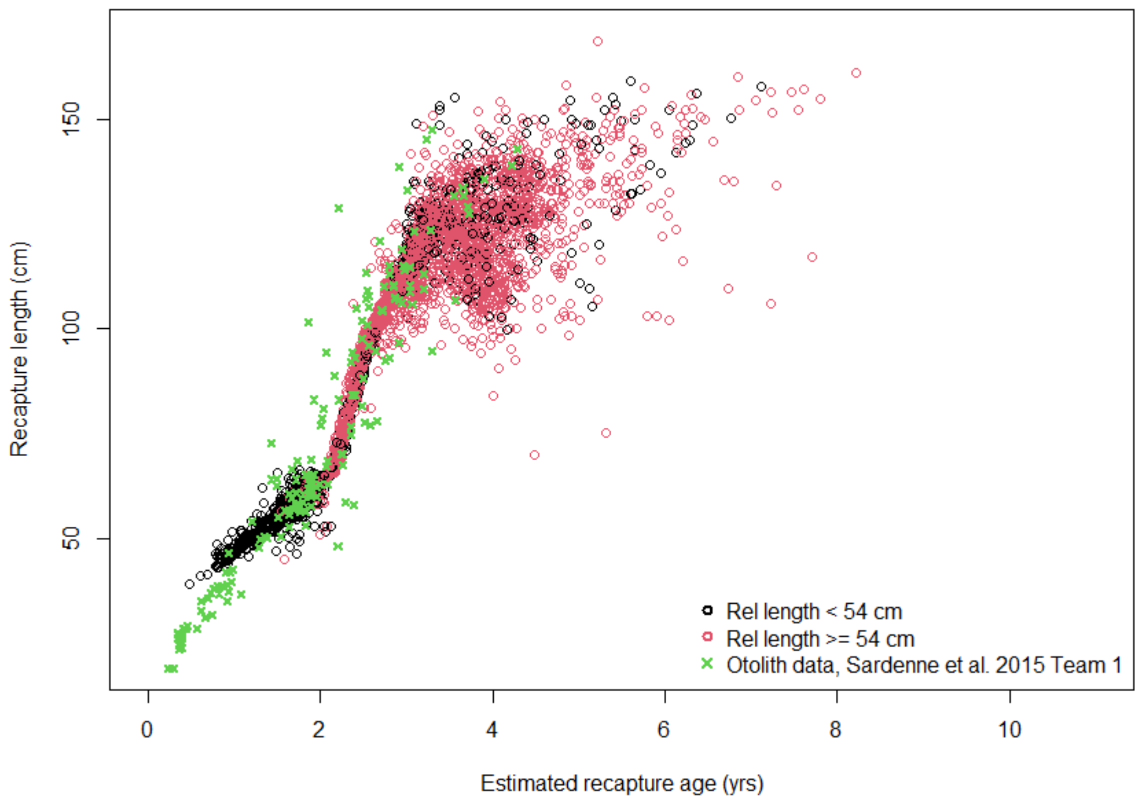


Figure 7. Recapture length versus recapture age as estimated for yellowfin tuna using release age derived from the length versus daily age relationship in Figure 5 plus the time at liberty. Data are colour-coded by release length (< 54 cm vs ≥54 cm). The otolith age and length data from the Farley et al. (2021a) are overlaid for comparison.



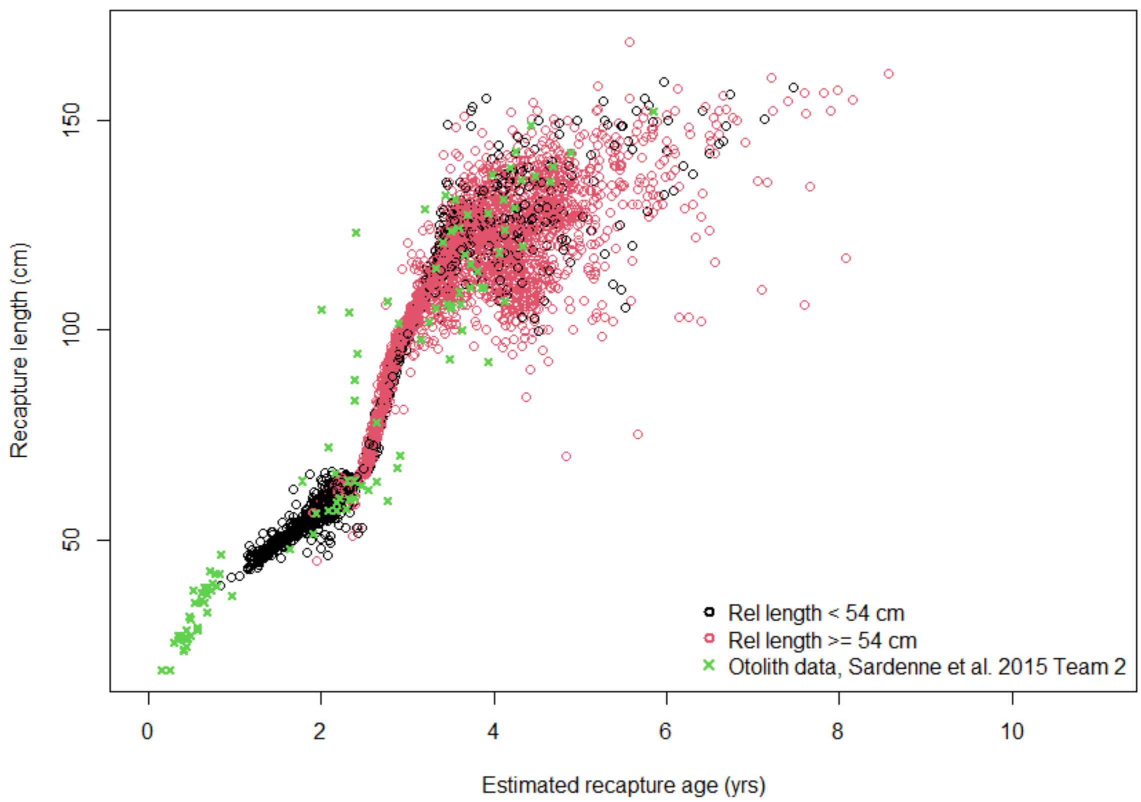
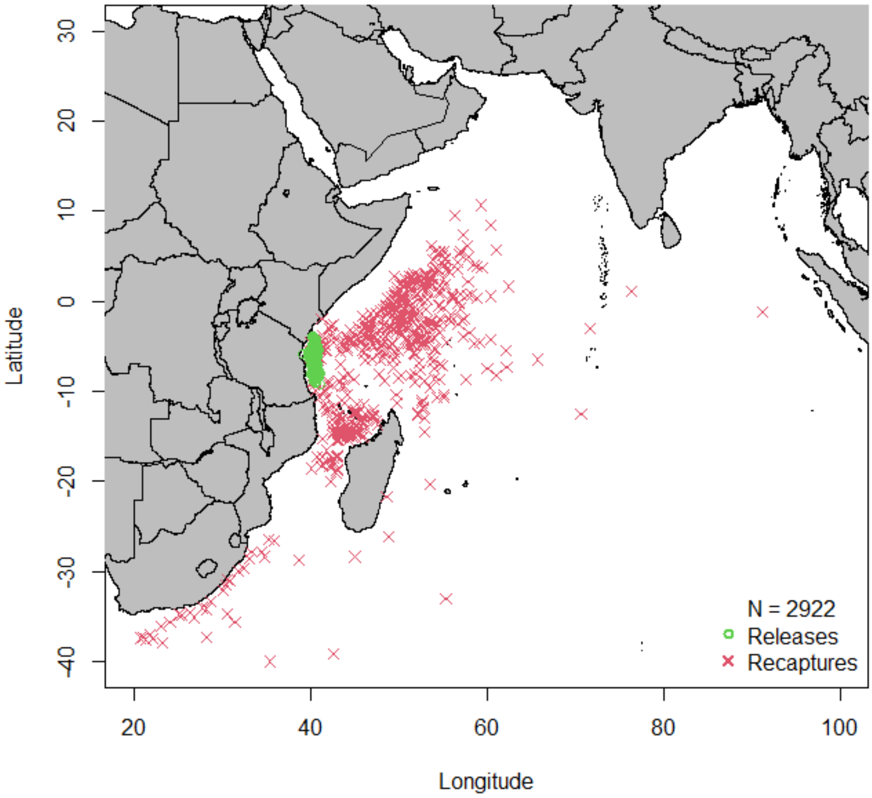


Figure 8. Recapture length versus recapture age as estimated for yellowfin tuna from the growth model in Eveson et al. (2015) which included tag-recapture data and otolith data from Sardenne et al. (2015) for reader Team 1 (top) or reader Team 2 (bottom). The otolith age and length data from Sardenne et al. (2015) for reader Team 1 (top) and reader Team 2 (bottom) are overlaid for comparison.

Figures – bigeye tuna



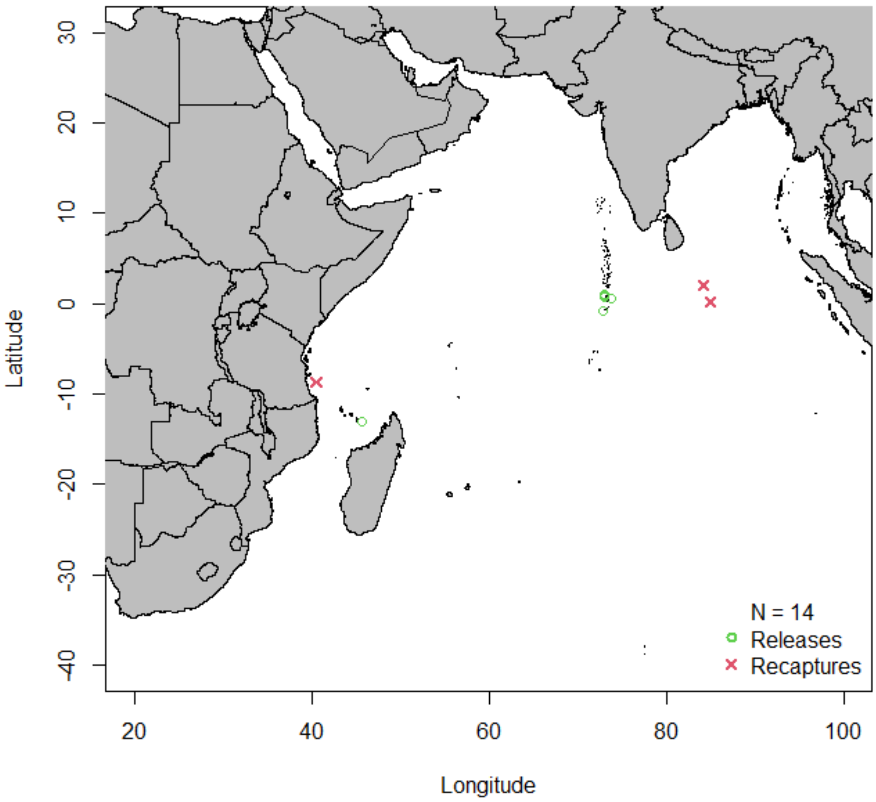


Figure 9. Map of the release and recapture locations for bigeye tuna used in the growth analysis of Eveson et al. (2015), showing fish that were released off Tanzania (top) and released elsewhere (bottom).

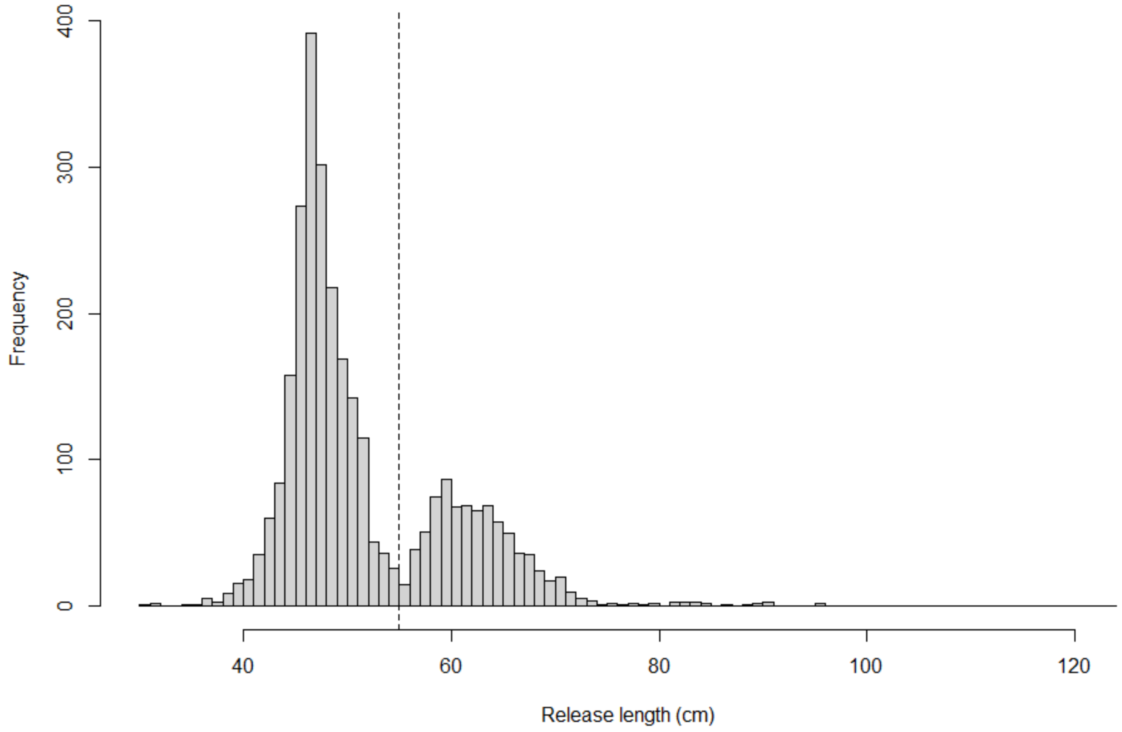


Figure 10. Release length distribution of bigeye tuna used in the growth analysis of Eveson et al. (2015). There is a separation between modes at 55 cm (dashed vertical line).

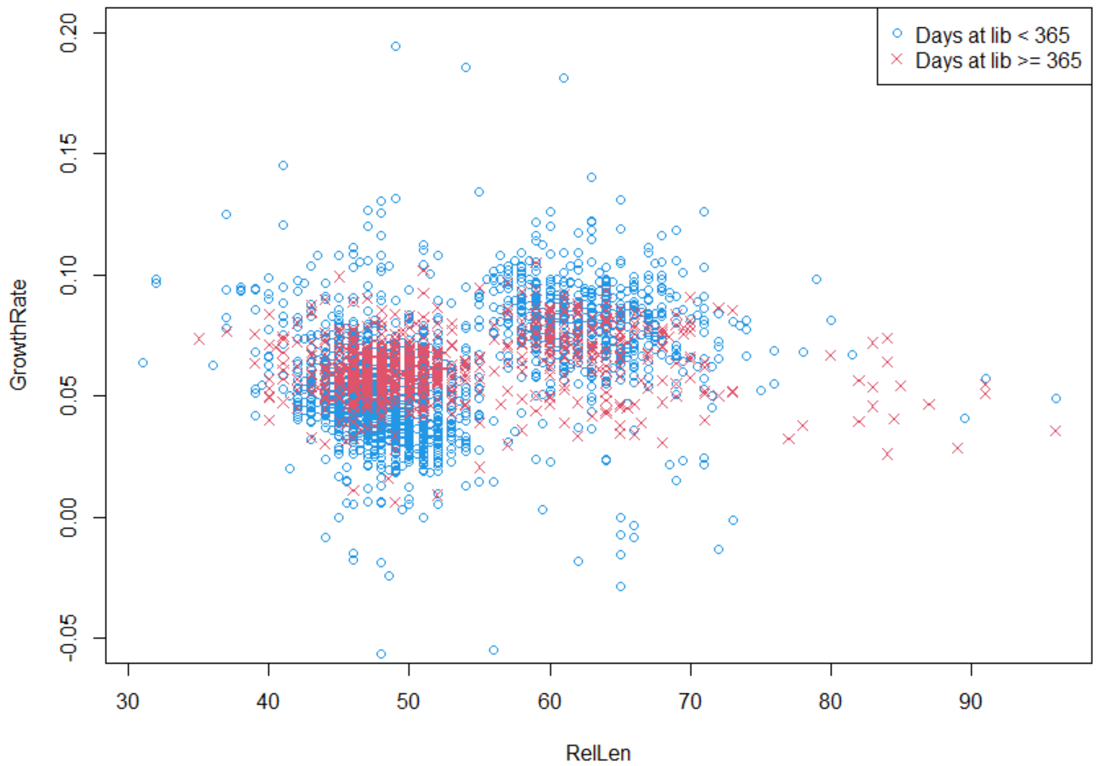


Figure 11. Growth rate (cm/day) versus release length (cm) for bigeye tuna, broken down by time at liberty (<365 days vs ≥365 days).

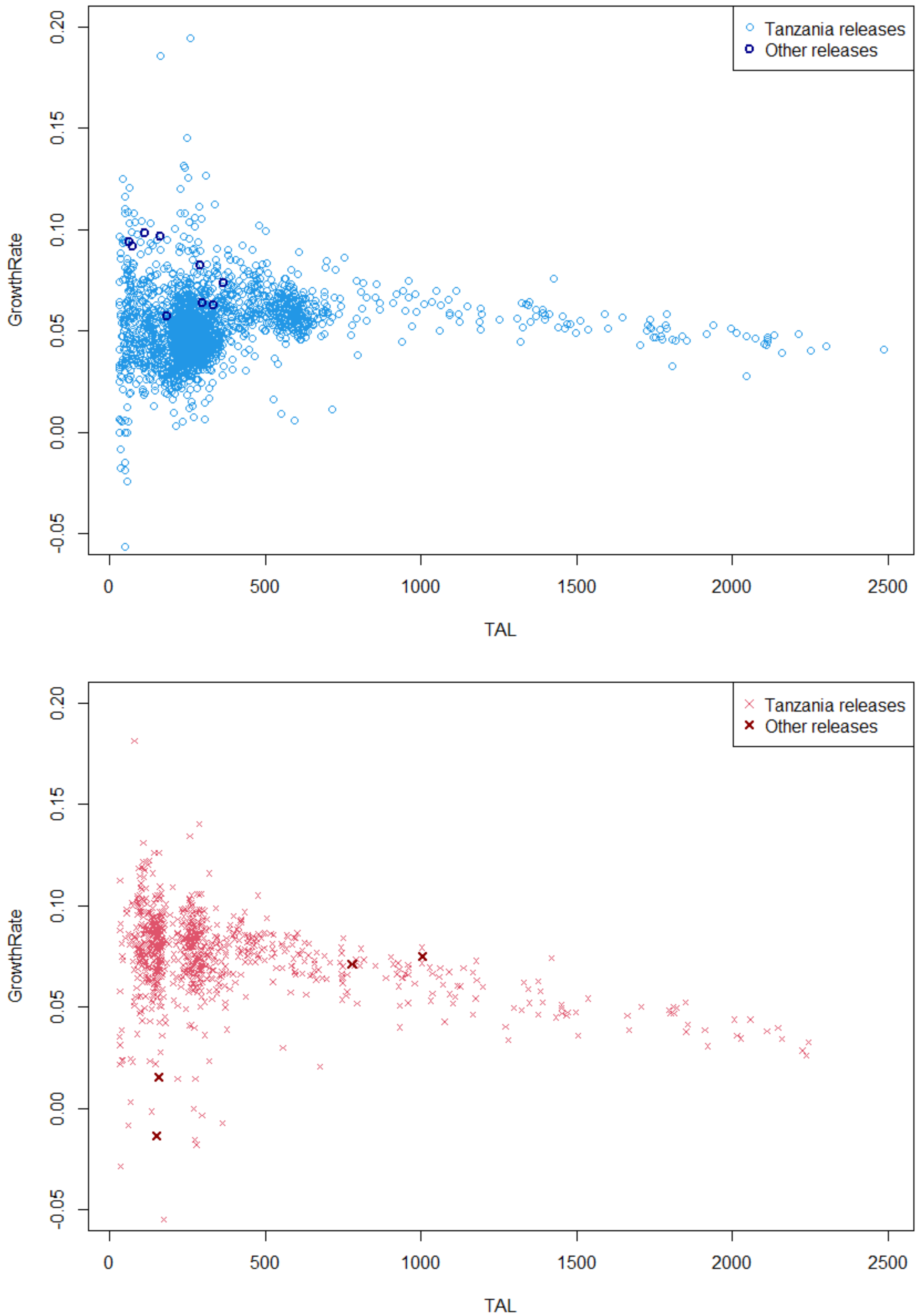


Figure 12. Growth rate (cm/day) versus time at liberty (TAL, days) for bigeye tuna that were <55 cm at release (top) and ≥55 cm at release (bottom). Those released in areas other than Tanzania are highlighted for comparison.

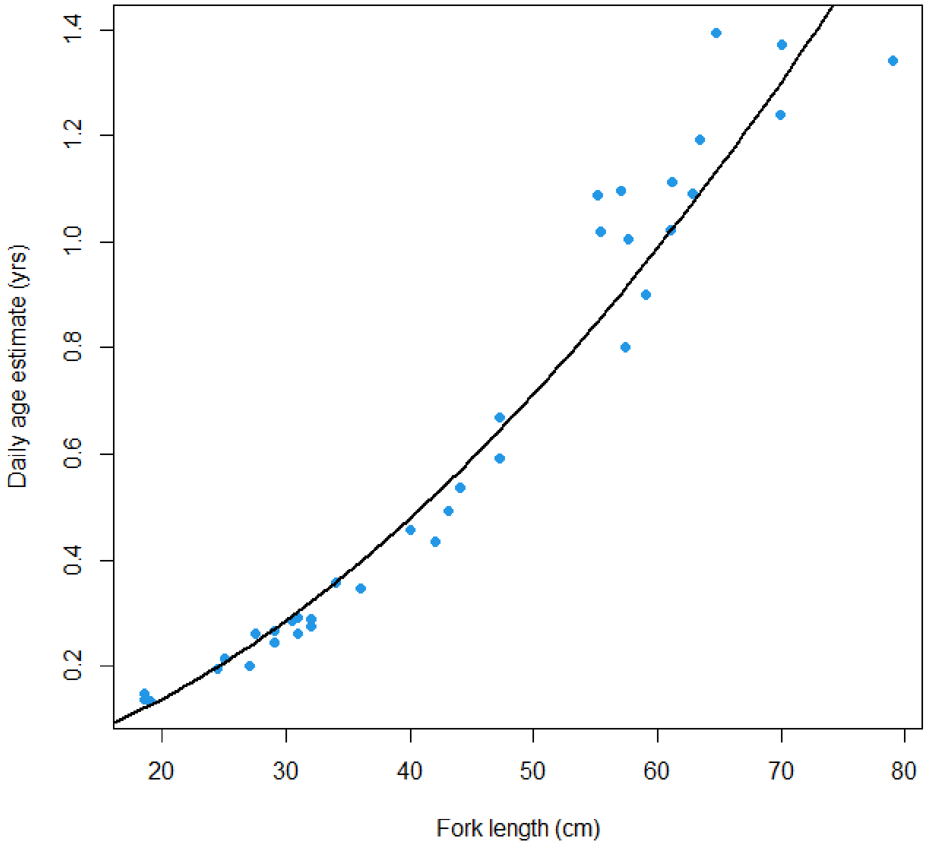
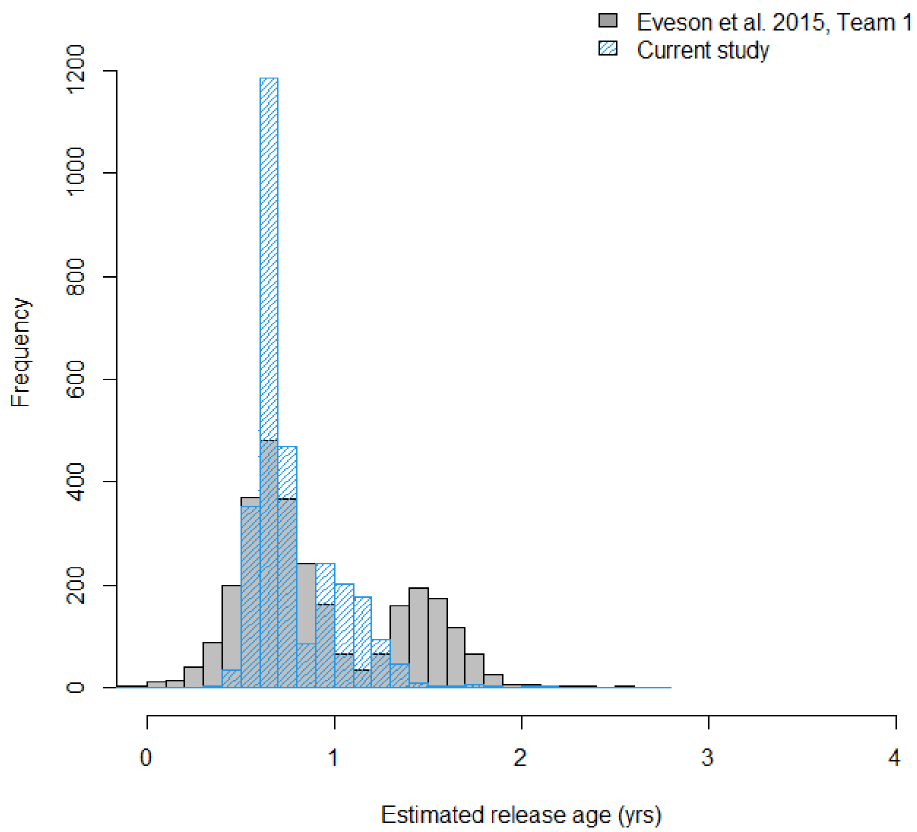


Figure 13. Fork length versus otolith daily age for bigeye tuna, with a power curve fitted to the data (taken from Farley et al. 2021b).



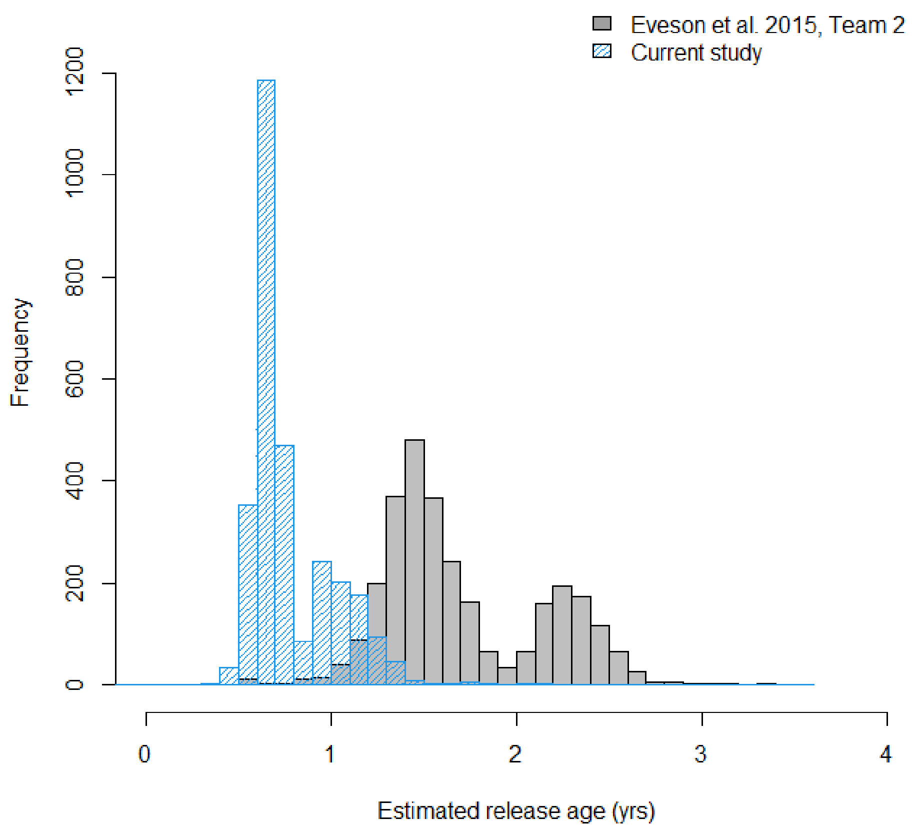


Figure 14. Histogram of release ages estimated for bigeye tuna in the current study using the length versus daily age relationship in Figure 5 (blue bars) compared to release ages estimated from the growth model in Eveson et al. (2015) (grey bars), which included tag-recapture data and otolith data from Sardenne et al. (2015) for reader Team 1 (top) or reader Team 2 (bottom).

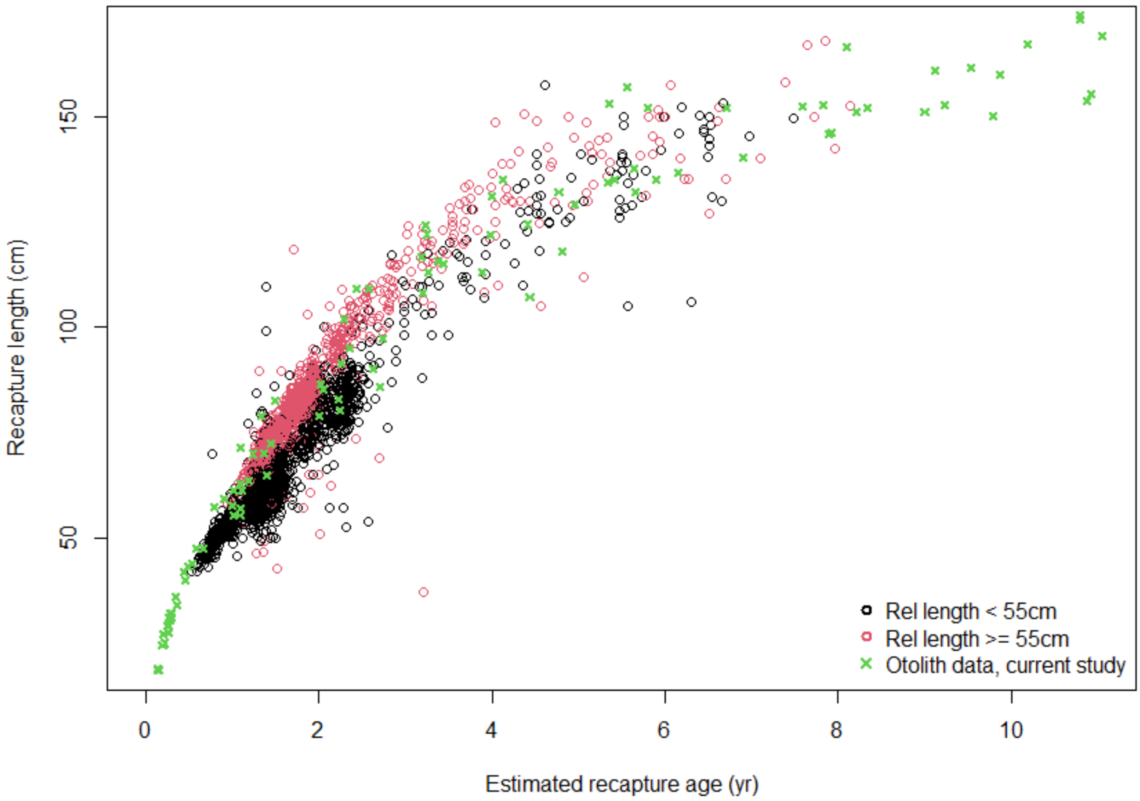


Figure 15. Recapture length versus recapture age as estimated for bigeye tuna using release age derived from the length vs daily age relationship in Figure 5 plus the time at liberty. Data are colour-coded by release length (< 54 cm vs ≥54 cm). The otolith age and length data from Farley et al. (2021b) are overlaid for comparison.

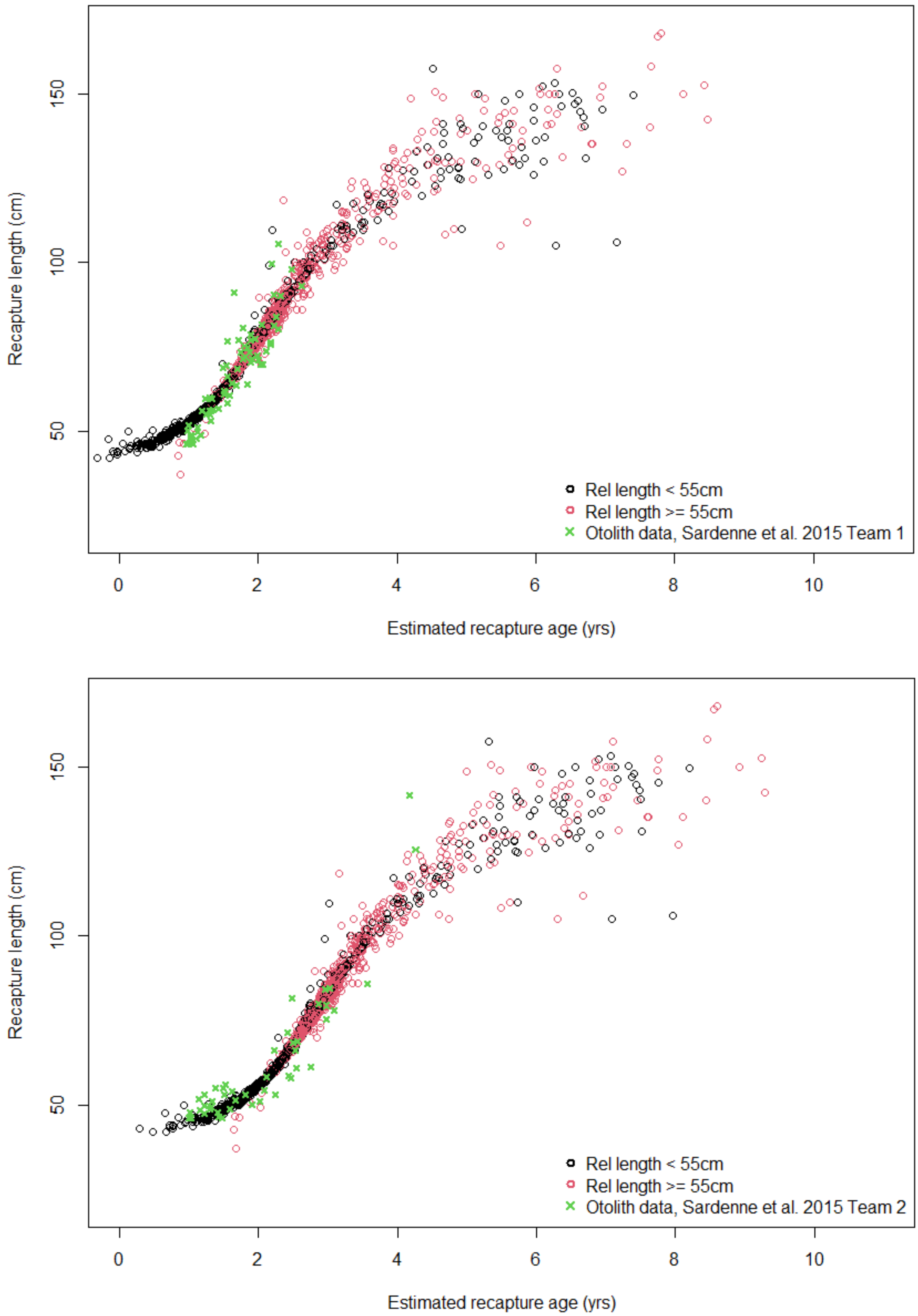


Figure 16. Recapture length versus recapture age as estimated for bigeye tuna from the integrated growth model in Eveson et al. (2015) using tag-recapture data and otolith data from Sardenne et al. (2015) for reader Team 1 (top) and reader Team 2 (bottom). The otolith age and length data from Sardenne et al. (2015) for reader Team 1 (top) and reader Team 2 (bottom) are overlaid for comparison.