Updated analysis of 2006/07 RTTP-IO tagging data for Skipjack

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1 Introduction

This document details analyses of tagging and catch data from the Indian Ocean Skipjack fishery, employing an age-structured model detailed in document IOTC-2008-WPTT-16, and implemented in IOTC-2008-WPTT-15. The model is used to estimate abundance and exploitation rates within a particular year. No recruitment is included: each cohort is simply tracked through the quarters in each year, according to the population, tag and recapture models.

The analyses presented in IOTC-2008-WPTT-15 are re-implemented here for 2006/07 using a more complete data set. In addition, alternative data scenarios are explored that may better reduce bias in the model results.

2 Age based population model

Annual population dynamics are analysed seperately for each year. We estimate the initial numbers-at-age in the first quarter for each age class and project the dynamics forward

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for the remainder of the year, allowing exploitation rates to be calculated.

2.1 Population dynamics

Given an estimate for the initial numbers at age in the first quarter $N_{q=1,a}$, the dynamics of $N_{q,a}$ for a given year, quarters $q = 2, ..., 4$ and ages $a = a_{\min}, ..., a_{\max}$ is given by:

$$N_{q,a} = N_{q-1,a} \exp(-M_a) \left(1 - \sum_{g=1}^{G} h_{g,q-1,a}\right) \tag{1}$$

where M is the natural mortality rate per age and h is the harvest/exploitation rate by gear-type g:

$$h_{g,q,a} = \frac{C_{g,q,a}}{N_{q,a} \exp(-M_a/2)} \tag{2}$$

assuming an instantaneous harvest in the middle of the quarter, where $C_{g,q,a}$ is the gear-specific catch at age.

2.2 Tag dynamics

Tagged fish $T_{q,a}$ are lost through natural and fishing mortality but also tag shedding, as well as differential vulnerabilities to the gear types over time (a pseudo-spatial effect given the dispersal times of tagged fish across the Indian Ocean). To account for these effects we describe a compound tag survival probability, π^{TS}:

$$\pi^{TS}_{y,q,a} = \exp(-M_a) \pi^R(\tau) \left(1 - \sum_{g} h_{y,g,q,a} \kappa(g, \tau, a)\right). \tag{3}$$

The τ parameter denotes time-at-liberty in years; $\pi^R(\tau)$ is the probability of retaining a tag up to the given time-at-liberty, τ; and $\kappa(g, \tau, a)$ is a function ranging from zero to one that denotes the vulnerability of the tagged animals to a given gear type, at a given age and for a given time-at-liberty. The value for $\kappa(g, \tau, a)$ incorporates a pseudo-spatial feature into the model allowing for differential mixing times of the tagged animals into the different gear types, given the spatially different locations of the fishing operations relative to the tag release point(s). We can now define the dynamics of the tagged animals following a release event:

$$T_{q,a} = T_{q-1,a}\pi^{TS}_{q-1,a} \tag{4}$$

with number of tags in a release event given by the actual number of releases.

3 Tag recapture models

We know that tagged animals are taken by all of the gear types but are consistently reported from catches by the European Union purse-seine fleet only. This is also the only fleet for which we have reporting rate information. The tag recapture models allow us to derive both an expected number of tag returns based on our tag population dynamics model, and an observed number of returns based on the actual number of recoveries. In both cases reporting rate information is required to derive the probability of reporting a tag (π^{det}).

3.1 Reporting rate

Tags from the European purse-seine fleet are collected at a number of different stages:

1. At the moment of catch by the crew (at sea recoveries).
2. At the moment of unloading/transhipping of the purse-seiner itself by stevedores in Seychelles, Madagascar, Kenya and Mauritius.
3. At the moment of unloading of a reefer on which the fish from the purse-seine had been transhipped, or during processing in a cannery. These recoveries can occur in Columbia, Cote d'Ivoire, Ecuador, Iran, Kenya, Madagascar, Mauritius, Seychelles, Spain or Thailand.

To be able to estimate the reporting rate a tag seeding operation was developed in 2004. Tags were implanted on the fish after they were caught and seeded in the wells of European Union purse-seiners, for which some were recovered at the different stages of unloading and processing (Stages 2 and 3). This allows estimation of the country specific reporting rate for tags collected from Stage 2 (only considering stevedore recaptures), or from Stages 2 and 3 combined (considering all recaptures during unloading and processing). The reporting rate for Stage 1 (at sea recaptures) cannot be estimated from tag seeding.

Having no control on the country of unloading, we have a good sample size of the seeded tags on skipjack in the Seychelles (1223 seeded and unloaded, 1130 recovered and reported - including recoveries from all stages), but small samples in Madagascar (55 vs. 45) and Kenya (29 vs. 14) and no sample in Mauritius (no seeded skipjack was unloaded in Mauritius). Standardised reporting rates ($\hat{\pi}^{\mathrm{det}}$) were estimated from this raw seeding and recovery data using the beta-binomial model described in WPTT-2008-18.

3.2 Observed tag returns

The number of observed tag returns is simply the number of recoveries from recovery Stage i, adjusted by the reporting rate for that stage:

$$R_{q,a} = \sum_i \frac{R^i_{q,a}}{\pi^{\mathrm{det,i}}} \tag{5}$$

3.3 Predicted tag returns

To predict the tag recaptures for the purse-seine fleet we use the catch associated with the tag recapture events (henceforth termed the reference catch, $C^{\mathrm{ref}}_{q,a}$) to define a probability of recovery for these tags π^r:

$$\pi^r_{q,a} = \frac{C^{\mathrm{ref}}_{q,a}}{N_{q,a}\exp\left(-M_a/2\right)} \times \bar{\pi}^{\mathrm{det}}, \tag{6}$$

where $\bar{\pi}^{\mathrm{det}}$ is the mean probability of detecting a tag across the different recapture Stages (derived from the reporting rate information above). The model-predicted number of tag returns is now simply

$$\widehat{R}_{q,a} = \pi^r_{q,a} T_{q,a}. \tag{7}$$

4 Estimation

When estimating the initial numbers at age for each age class $N_{1,a}$, we compare the predicted and observed number of recaptures using the poisson likelihood. Estimation used a Bayesian approach, implemented using MCMC. Priors for all abundance indices were improper uniform in the sense that any value of the abundance parameters would have the same prior density.

4.1 Poisson model

The predicted and observed number of tags were compared using a Poisson probability model. Assuming a pure Poisson process the probability/likelihood of each recapture event (for a given release event t) is given by:

$$p\left(R_{q,a,t_r} \mid \widehat{R}_{q,a,t_r}\right) = \frac{\left(\widehat{R}_{q,a,t_r}\right)^{R_{q,a,t_r}} \exp\left(-\widehat{R}_{q,a,t_r}\right)}{R_{q,a,t_r}!}. \tag{8}$$

Each release event, and subsequent recapatures, is treated in isolation. Our log-likelihood therefore takes the following form:

$$\log \mathcal{L} = \sum_{t=1}^{T} \sum_{tr=1}^{TR_t} \sum_{a} p\left(R_{t,tr,a} \mid \widehat{R}_{t,tr,a}\right), \tag{9}$$

where T is the number of release events and TR_t is the number of tag recapture events for tagging event t.

4.2 Penalties

We define two penalties for this estimation model framework:

- **Catch penalty**: for each instance where the total harvest rate (summed over all gears) is greater than or equal to one (i.e. there is more catch than fish) -100 is added to the log-likelihood
- **Tag penalty**: for each instance where there are not enough fish to tag in any given release event -100 is added to the log-likelihood

These two penalties would act so as to strongly discourage the estimator from going into areas of parameter space that violate these two principles. The log-posterior distribution is now simply the sum of the log-likelihood, log-prior and the log-penalties and a Metropolis-within-Gibb's sampler is employed to sample from the posterior distribution.

5 Data

5.1 Length to age conversion

All catch and tagging data were available by length in 1 cm length bins. Data were collated according to the upper and lower length bounds associated with age classes 2 to 5, using the von Bertalanffy growth curve with parameters $k = 0.288$, $L_\infty = 74.8cm$ (estimated from the tag data (Hillary, 2010)) and $t_0 = -0.5$ (assumed) .

5.2 Catch data

Catch data-at-age for ages 2 to 5 was broken down as follows:

1. Reference catch (numbers - $C^{\text{ref}}_{q,a}$, Equation 6) directly associated to the tag recapture data used.
2. Catch (numbers - $C_{q,a}$, Equation 2) for Purse Seine LS and FS, Baitboat, Gillnet and Other fleets.

5.3 Tag data

A number of options exist for aggregation and analysis of the tag recapture data, which are available from European Union purse-seine at sea recaptures (R^1), and by country for stevedore landed catches (R^2) and canneries and reefers (R^3). Each Option considers data from different sources and different countries. Thus R^2 and R^3 should be considered in context as referring to the country or countries specified. Where necessary we assume the reporting rate for at sea recoveries to be 1 ($\pi^{\text{det},1} = 1$) and estimate the reporting rate for the country specific stevedores ($\pi^{\text{det},2}$) or the overall reporting rate ($\pi^{\text{det},2,3}$).

Option 1

Reference catch: European Union purse-seine catches landed in the Seychelles

Reporting rate: Seychelles stevedore only

Recaptures: At-sea European Union Purse Seine recaptures and Seychelles stevedore only (no other country, no recoveries on reefers or in canneries). Thus the observed number of recaptures for a given year is $R_{q,a} = R^1_{q,a} + \frac{R^2}{\hat{\pi}^{\text{det},2}}$. The predicted tag returns are estimated using $\bar{\pi}^{\text{det}} = \frac{1+\hat{\pi}^{\text{det},2}}{2}$.

There are good data on reporting rate estimates for the stevedores in the Seychelles, however, because some of the European Union catch goes to other ports (Mauritius/Kenya/Madagascar) the reference catch will be an underestimate and exploitation rates will be biased upwards.

Option 2

Reference catch: European Union purse-seine catches landed in the Seychelles

Reporting rate: Seychelles stevedore only

Recaptures: Seychelles stevedore recaptures only. Thus the observed number of recaptures for a given year is $R_{q,a} = \frac{R^2_{q,a}}{\hat{\pi}^{\text{det},2}}$, and $\bar{\pi}^{\text{det}} = \hat{\pi}^{\text{det},2}$.

In this case the number of recaptures will be underestimated because some tags will have been removed from the catch at sea prior to landing them in the Seychelles. Thus exploitation rates will be biased downwards.

Option 3

Reference catch: All European Union purse-seine catches

Reporting rate: All tag seeding data

Recaptures: At-sea European Union Purse Seine recaptures and all recaptures from stevedores in the Seychelles, Mauritius, Kenya and Madagascar (only the European Union fleet lands at these ports), reefers and cannery workers. Thus the observed number of recaptures for a given year is $R_{q,a} = R^1_{q,a} + \frac{R^2_{q,a}+R^3_{q,a}}{\pi^{\mathrm{det},2,3}}$, and and $\bar{\pi}^{\mathrm{det}} = \frac{1+\hat{\pi}^{\mathrm{det},2,3}}{2}$.

This approach should provide an unbiased estimate of exploitation rates.

Option 1 correponds to the analysis conducted in 2008 (IOTC-2008-WPTT-15). However, because of the bias involved, it was decided to repeat the analysis under Option 3, whilst retaining Option 1 for comparitive purposes. Repetition of Option 1 was also justified on the basis that the data used in WPTT-2008-15 was incomplete at the time of analysis. Option 2 was not considered worthwhile. Release and recapture data for Options 1 and 3 are given in Tables 1, 2 and 3. Standardised reporting rates ($\hat{\pi}^{\mathrm{det}}$) are given in Table 4.

5.4 Model assumptions

Within season recaptures were not used in the model (an assumption of 3 months mixing time of tags into the purse-seine fleet). In addition we make the following assumptions:

1. Natural mortality rate of $M_1 = 0.2$ and $M_{2+} = 0.15$.

2. The tag retention rate (Equation 3) of $\pi^R(\tau) = \phi e^{-\mu\tau}$ with $\phi = 0.984$ and $\mu = 0.016$ (IOTC-2008-WPTDA-04).

3. The rate of dispersion (Equation 3) of:

   Purse seine fleet $\kappa(g, \tau, a) = 1$ for $tau > 0$

   Baitboat, Gillnet and Other fleets $\kappa(g, \tau, a) = 1$ for $tau > 0.5$

6 Summary statistics

Outputs for the model consist of estimated numbers at age for the first quarter of each year, and the harvest rate per quarter for each gear. The harvest rate across gear types is given by:

$$h_{q,a} = 1 - \prod_{g} (1 - h_{g,q,a}) \tag{10}$$

From these harvest rates for each quarter we calculate the annual harvest rate as a weighted average of the harvest rates by quarter. The weighting accounts for the number of individuals that will have survived to a given quarter. The annual harvest rate is therefore given by:

$$\begin{aligned} \bar{h}_a = h_{1,a} + e^{-M_a}(1 - h_{1,a})h_{2,a} + e^{-2M_a}(1 - h_{1,a})(1 - h_{2,a})h_{3,a} \\ + e^{-3M_a}(1 - h_{1,a})(1 - h_{2,a})(1 - h_{3,a})h_{4,a} \end{aligned} \tag{11}$$

7 Results and Discussions

Results for Options 1 and 3 are given in Tables 5 to 8, and illustrated in Figures 1 to 4. Annual harvest rates are illustrated in Figures 5 and 6. These are appropriate for comparison to fishing mortality based reference points for Skipjack (using the Baranov catch equation to numerically estimate F_a from the harvest rates listed: $H_a = \frac{F_a}{F_a+M_a}(1 - e^{-F_a-M_a})$). Model fits are given in Figures 7 to 10. Notably estimated exploitation rates are similar between the two Options, illustrating the results are robust to different assumptions surrounding the data. We conclude that any bias present in previous work is likely to be small.

As with the model presented in IOTC-2008-WPTT-15, this updated model estimated abundances of skipjack to be large (for 2006 and 2007): larger than estimates of recruits of both bigeye and yellowin. Exploitation rates estimated for both model options are generally fairly low - only exceeding 20% for ages 3 and 4 for 2007. For both options, abundances in 2006 are predicted to be higher than those in 2007. The stable age-structure apparent in both years is again noted here (there is a very similar decrease in relative abundance from ages 2 to 5). This would imply a reasonably stable year-class regime at least for the cohorts that encompass these data (2000-2005).

References

Hillary, R. M. 2010. A New Method for Estimating Growth Transition Matrices. Biometrics **10.1111/j.1541-0420.2010.01411.x**.

		Age			
Year	Quarter	2	3	4	5
2006	1	419	8343	1859	388
	2	209	4761	1908	440
	3	5418	6609	670	107
2007	1	11	112	81	4
	2	192	1835	1807	616
	3	3980	10707	1616	177

Table 1: Tag releases

Year	Quarter Release	Quarter Recapture	Age 1	2	3	4
2006	1	1	31	303	48	7
		2	14	357	58	8
		3	9	126	31	3
		4	11	187	21	2
	2	1	0	0	0	0
		2	2	60	11	2
		3	4	149	81	19
		4	7	245	92	9
	3	1	0	0	0	0
		2	0	0	0	0
		3	10	9	5	1
		4	86	179	13	0
2007	1	1	5	35	18	1
		2	2	1	1	0
		3	0	1	2	0
		4	0	0	1	0
	2	1	0	0	0	0
		2	0	4	0	0
		3	14	226	146	5
		4	3	73	43	10
	3	1	0	0	0	0
		2	0	0	0	0
		3	109	402	68	5
		4	78	400	38	3

Table 2: **Option 1**. Tag recaptures

Year	Quarter	Quarter	Age			
	Release	Recapture	1	2	3	4
2006	1	1	35	364	59	12
		2	18	487	85	14
		3	9	152	37	4
		4	11	216	24	2
	2	1	0	0	0	0
		2	2	65	13	2
		3	4	173	101	18
		4	7	279	112	10
	3	1	0	0	0	0
		2	0	0	0	0
		3	9	11	6	1
		4	90	197	18	0
2007	1	1	5	37	18	1
		2	2	1	1	0
		3	0	1	2	0
		4	0	0	1	0
	2	1	0	0	0	0
		2	0	4	0	0
		3	13	226	148	5
		4	4	78	41	10
	3	1	0	0	0	0
		2	0	0	0	0
		3	112	416	67	5
		4	79	437	43	3

Table 3: **Option 3**. Tag recaptures

Year	Option 1					Option 3				
	Seeded	Recovered	π^{det}	$\hat{\pi}^{\text{det}}$	$\bar{\pi}^{\text{det}}$	Seeded	Recovered	π^{det}	$\hat{\pi}^{\text{det}}$	$\bar{\pi}^{\text{det}}$
2004	14	2	0.14	0.15	0.58	22	8	0.36	0.37	0.69
2005	176	67	0.38	0.38	0.69	216	141	0.65	0.65	0.83
2006	309	279	0.9	0.9	0.95	311	299	0.96	0.96	0.98
2007	515	470	0.91	0.91	0.96	542	530	0.98	0.98	0.99
2008	180	152	0.84	0.84	0.92	199	191	0.96	0.96	0.98
2009	29	24	0.83	0.82	0.91	30	27	0.9	0.89	0.95

Table 4: Reporting rate estimates for Options 1 and 3

Year	Quarter	Age							
		2	*cv*	3	*cv*	4	*cv*	5	*cv*
2006	1	672.8	(0.077)	306.5	(0.026)	174.1	(0.053)	120.8	(0.16)
	2	541.1	(0.079)	258.3	(0.027)	146.3	(0.054)	103.2	(0.161)
	3	425.7	(0.082)	212.6	(0.028)	120.4	(0.056)	87	(0.165)
	4	321.3	(0.089)	175.1	(0.029)	102.3	(0.057)	74.5	(0.166)
2007	1	515.1	(0.095)	133.7	(0.03)	56.3	(0.051)	61.7	(0.238)
	2	412.9	(0.097)	111.3	(0.031)	45.8	(0.054)	52.5	(0.241)
	3	327.4	(0.1)	88.5	(0.034)	34.7	(0.061)	44.2	(0.246)
	4	259	(0.103)	68.8	(0.037)	26.4	(0.069)	37.2	(0.252)

Table 5: **Option 1**. Numbers-at-age (millions)

Year	Quarter	Age							
		2	*cv*	3	*cv*	4	*cv*	5	*cv*
2006	1	0.02	(0.077)	0.02	(0.026)	0.02	(0.052)	0.01	(0.153)
	2	0.04	(0.078)	0.04	(0.027)	0.04	(0.053)	0.02	(0.154)
	3	0.08	(0.08)	0.04	(0.028)	0.01	(0.056)	0	(0.158)
	4	0.07	(0.088)	0.07	(0.029)	0.03	(0.056)	0.01	(0.158)
	All	0.13	(0.076)	0.13	(0.026)	0.09	(0.052)	0.03	(0.153)
2007	1	0.02	(0.094)	0.03	(0.03)	0.05	(0.05)	0.01	(0.228)
	2	0.03	(0.095)	0.08	(0.031)	0.12	(0.053)	0.02	(0.231)
	3	0.03	(0.098)	0.1	(0.033)	0.11	(0.06)	0.02	(0.237)
	4	0.04	(0.102)	0.1	(0.037)	0.16	(0.068)	0.02	(0.243)
	All	0.09	(0.093)	0.21	(0.03)	0.30	(0.05)	0.06	(0.228)

Table 6: **Option 1**. Harvest rates-at-age

Year	Quarter	Age							
		2	*cv*	3	*cv*	4	*cv*	5	*cv*
2006	1	666.1	(0.073)	274	(0.023)	151.3	(0.047)	111	(0.143)
	2	535.6	(0.074)	230.4	(0.024)	126.6	(0.048)	94.7	(0.144)
	3	421.2	(0.077)	188.6	(0.025)	103.5	(0.05)	79.7	(0.148)
	4	317.6	(0.084)	154.4	(0.027)	87.8	(0.051)	68.2	(0.148)
2007	1	545.5	(0.095)	129.9	(0.03)	59.4	(0.05)	71.3	(0.234)
	2	437.7	(0.097)	108	(0.031)	48.5	(0.053)	60.8	(0.236)
	3	347.7	(0.1)	85.7	(0.033)	37.1	(0.059)	51.3	(0.241)
	4	275.6	(0.103)	66.3	(0.037)	28.4	(0.067)	43.3	(0.245)

Table 7: **Option 3**. Numbers-at-age (millions)

Year	Quarter	Age							
		2	*cv*	3	*cv*	4	*cv*	5	*cv*
2006	1	0.02	(0.072)	0.02	(0.023)	0.03	(0.046)	0.01	(0.139)
	2	0.04	(0.073)	0.05	(0.024)	0.05	(0.048)	0.02	(0.14)
	3	0.08	(0.075)	0.05	(0.025)	0.02	(0.05)	0	(0.143)
	4	0.07	(0.081)	0.08	(0.026)	0.04	(0.051)	0.01	(0.144)
	All	0.13	(0.071)	0.14	(0.023)	0.10	(0.046)	0.04	(0.139)
2007	1	0.02	(0.094)	0.03	(0.029)	0.05	(0.05)	0.01	(0.225)
	2	0.03	(0.096)	0.08	(0.03)	0.11	(0.052)	0.02	(0.227)
	3	0.03	(0.099)	0.1	(0.032)	0.11	(0.059)	0.02	(0.232)
	4	0.04	(0.102)	0.1	(0.036)	0.15	(0.066)	0.02	(0.237)
	All	0.08	(0.094)	0.21	(0.029)	0.28	(0.05)	0.05	(0.225)

Table 8: **Option 3**. Harvest rates-at-age

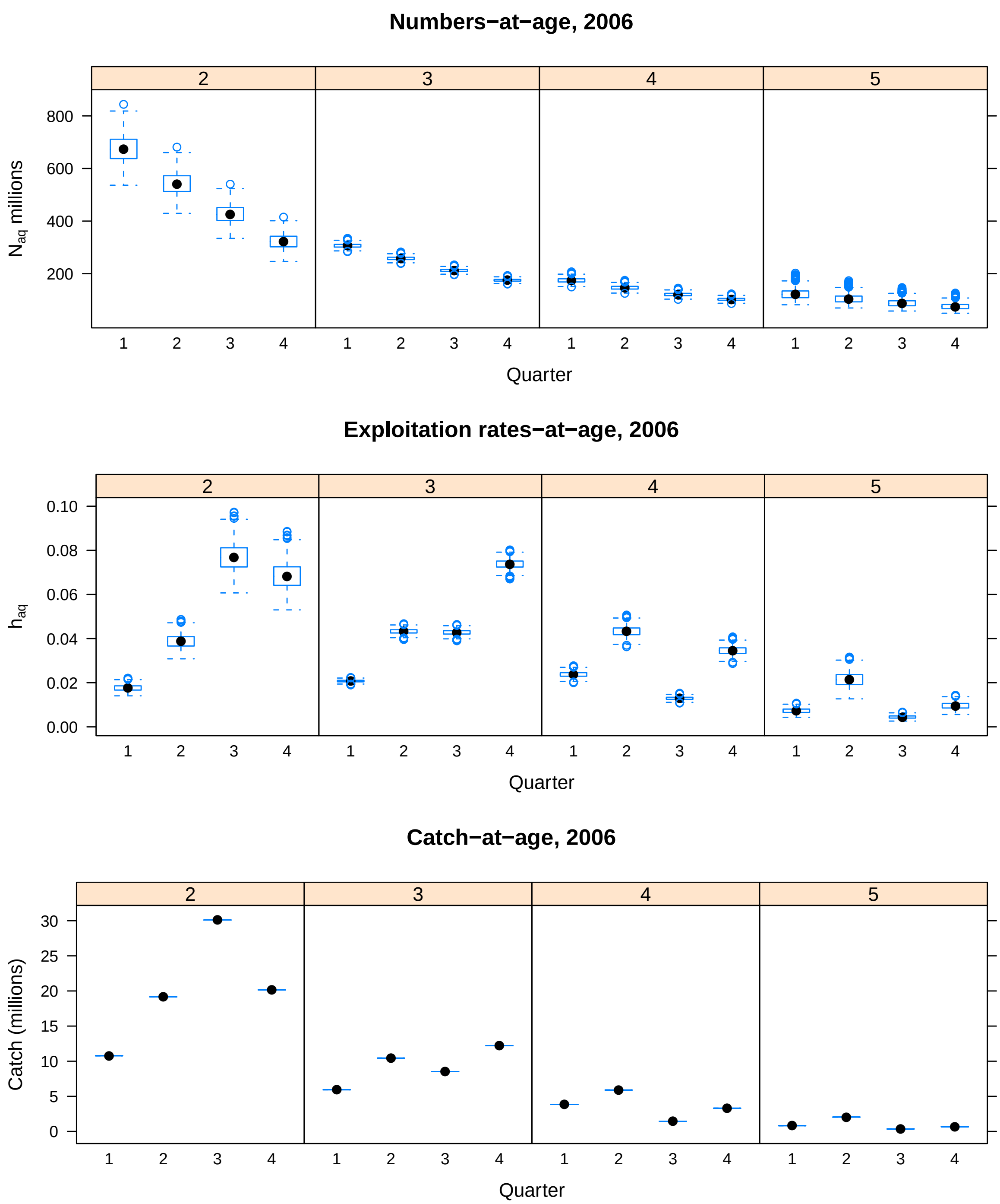

Figure 1: **Option 1**. Numbers, exploitation rates-at-age and catches by quarter for 2006

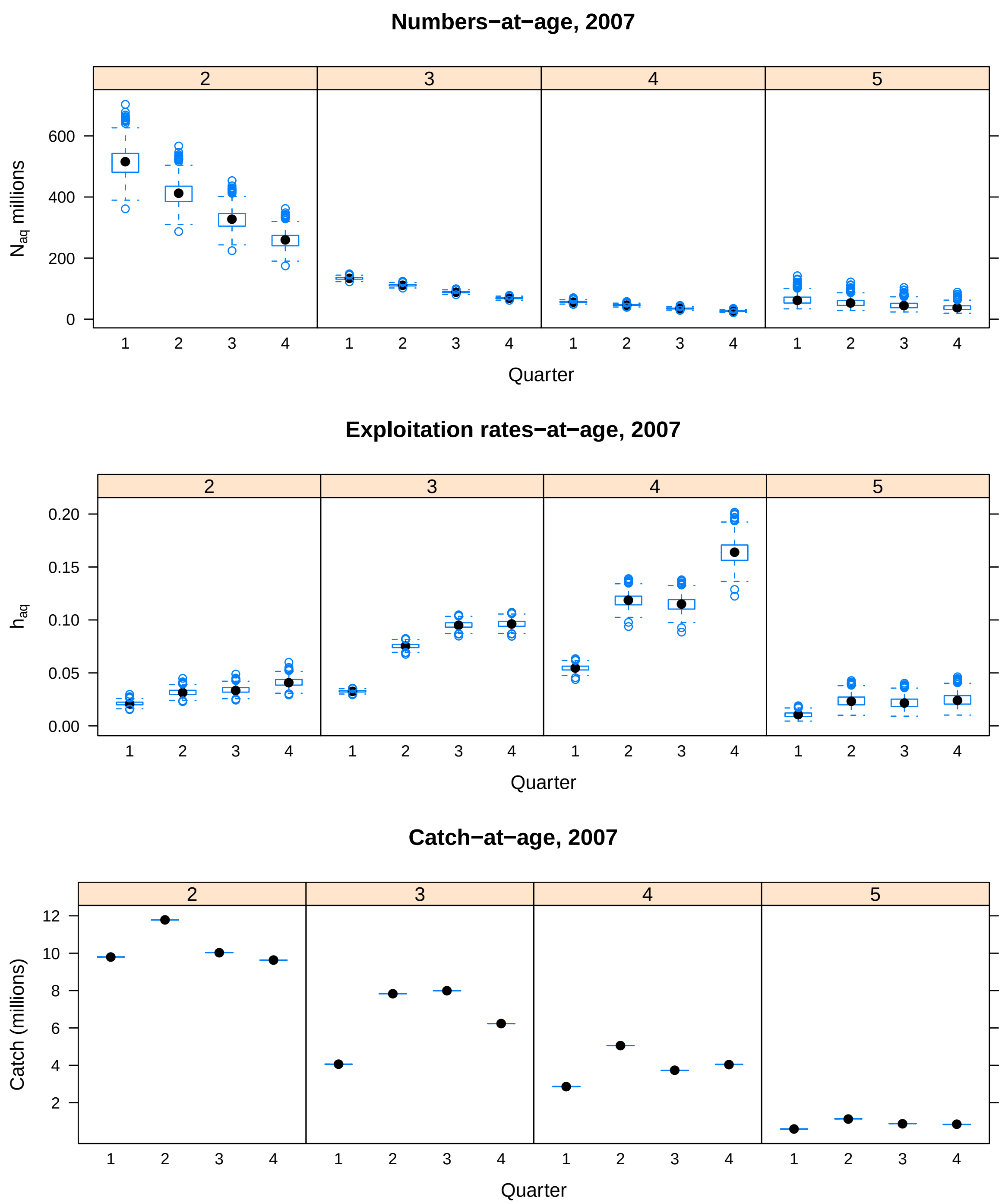

Figure 2: **Option 1**. Numbers, exploitation rates-at-age and catches by quarter for 2007

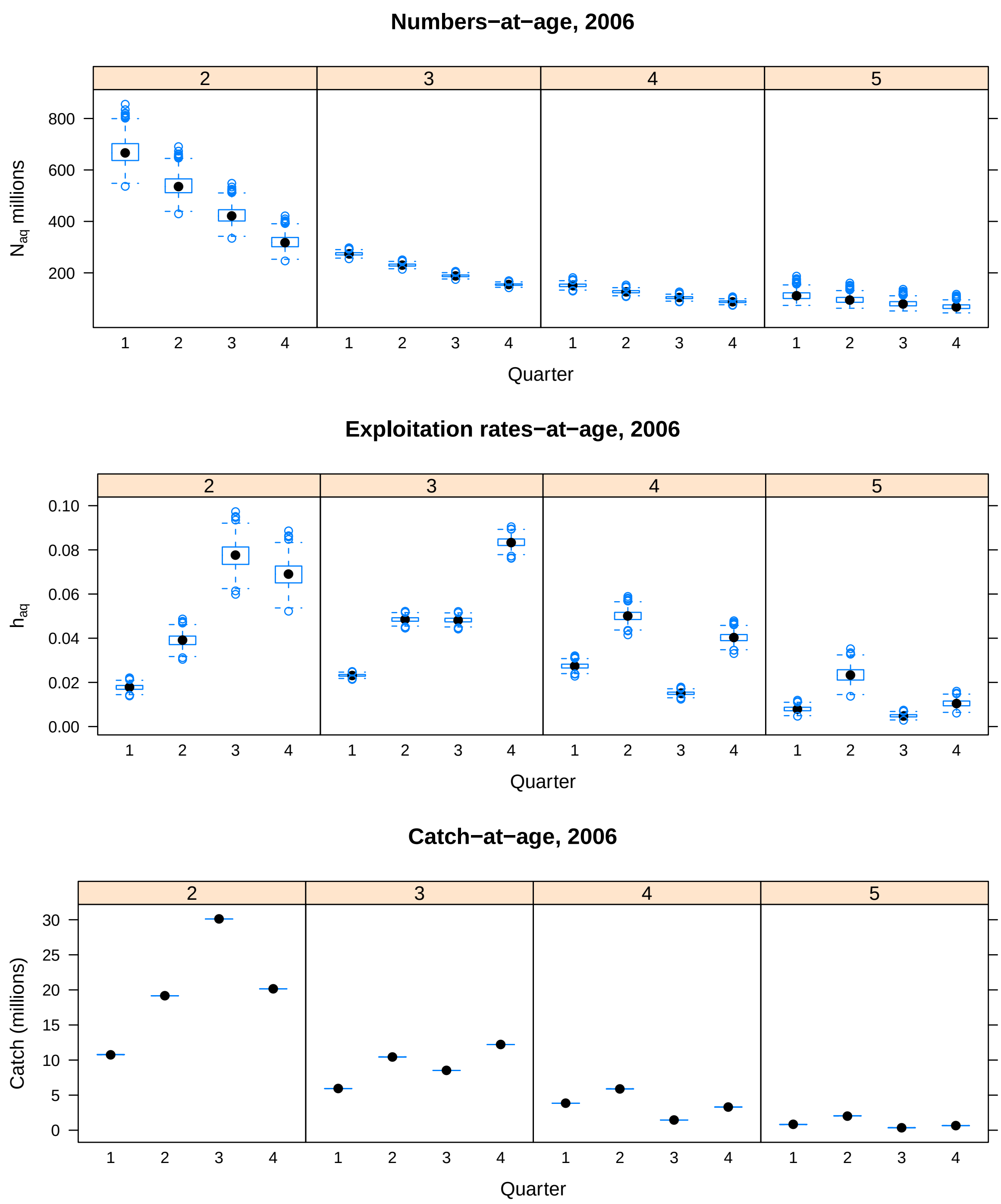

Figure 3: **Option 3**. Numbers, exploitation rates-at-age and catches by quarter for 2006

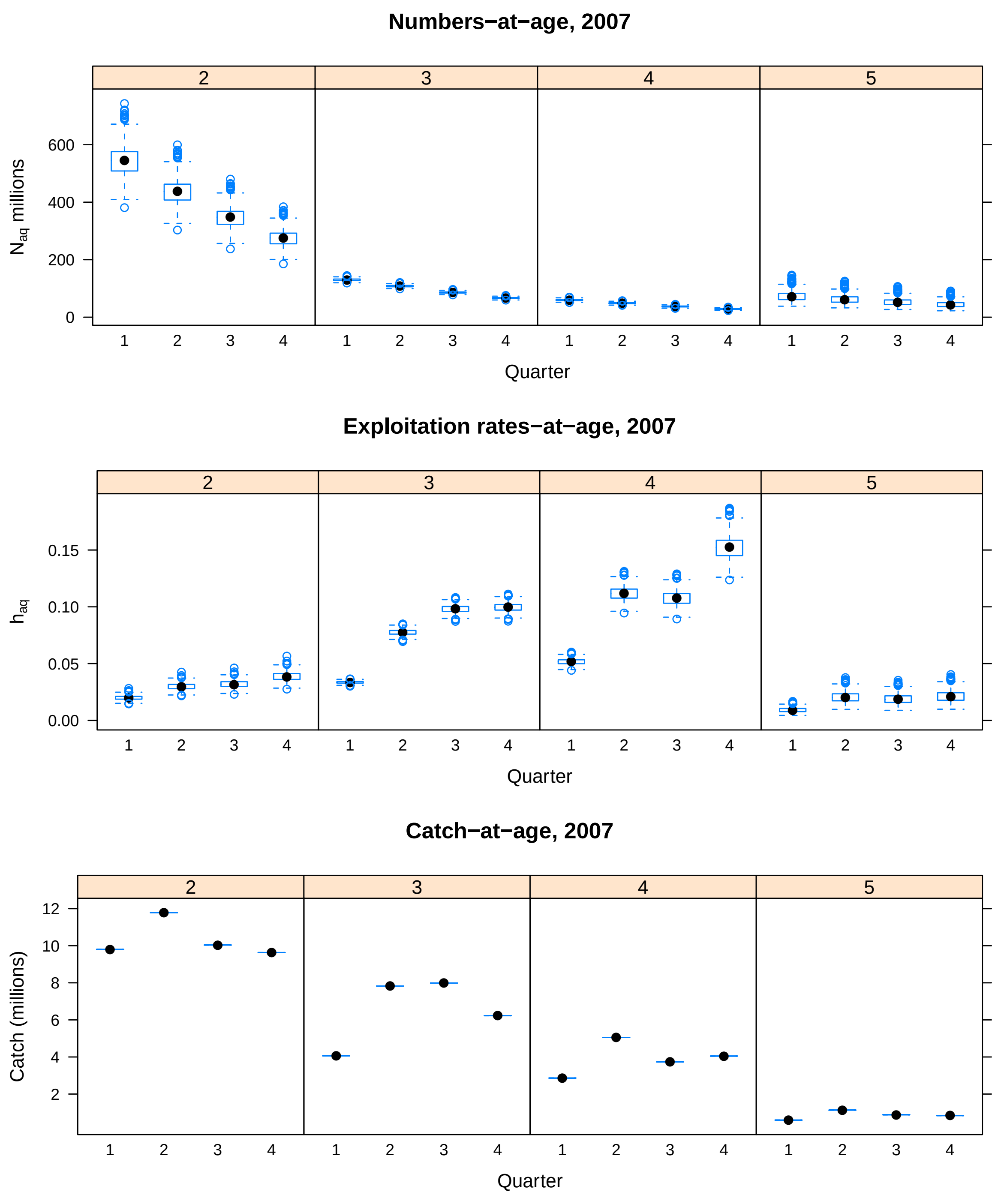

Figure 4: **Option 3**. Numbers, exploitation rates-at-age and catches by quarter for 2007

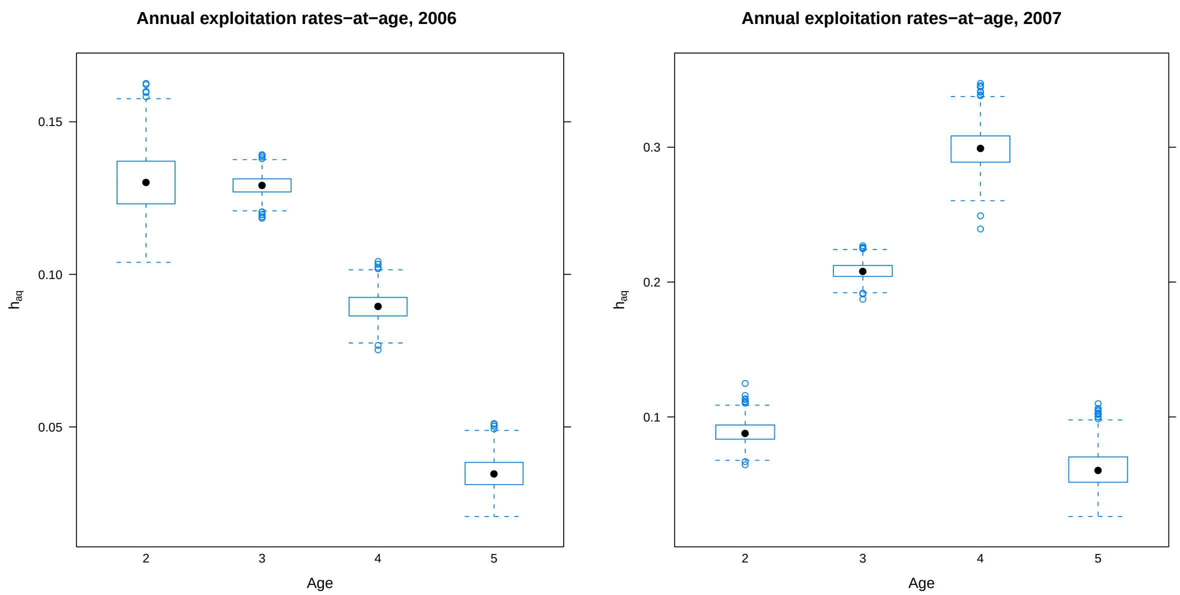

Figure 5: **Option 1**. Annual harvest rates

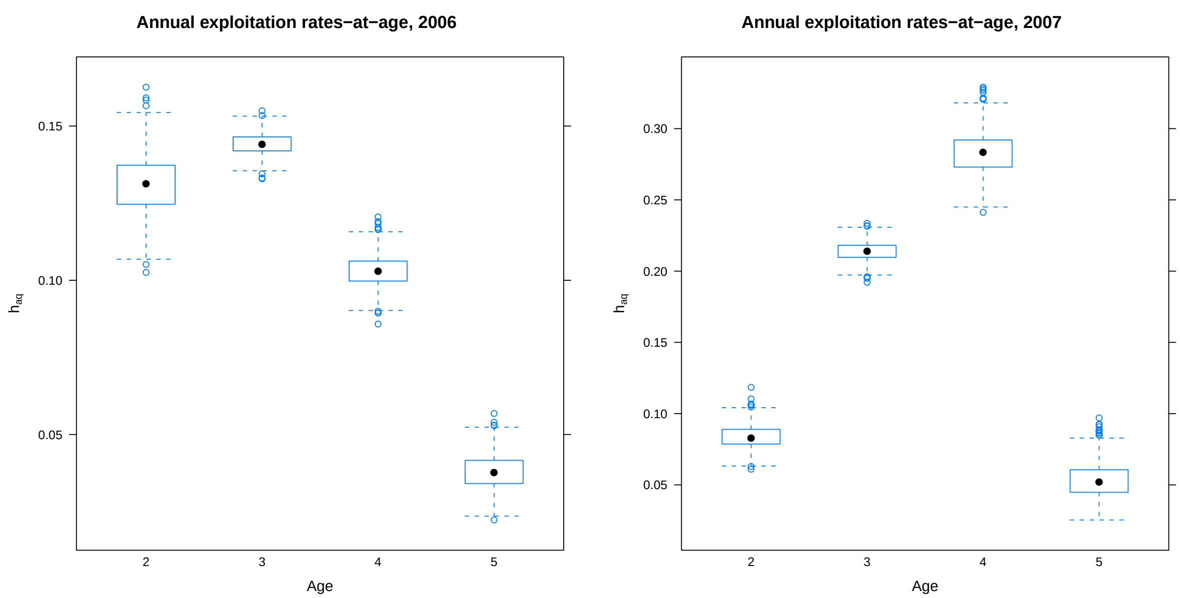

Figure 6: **Option 3**. Annual harvest rates

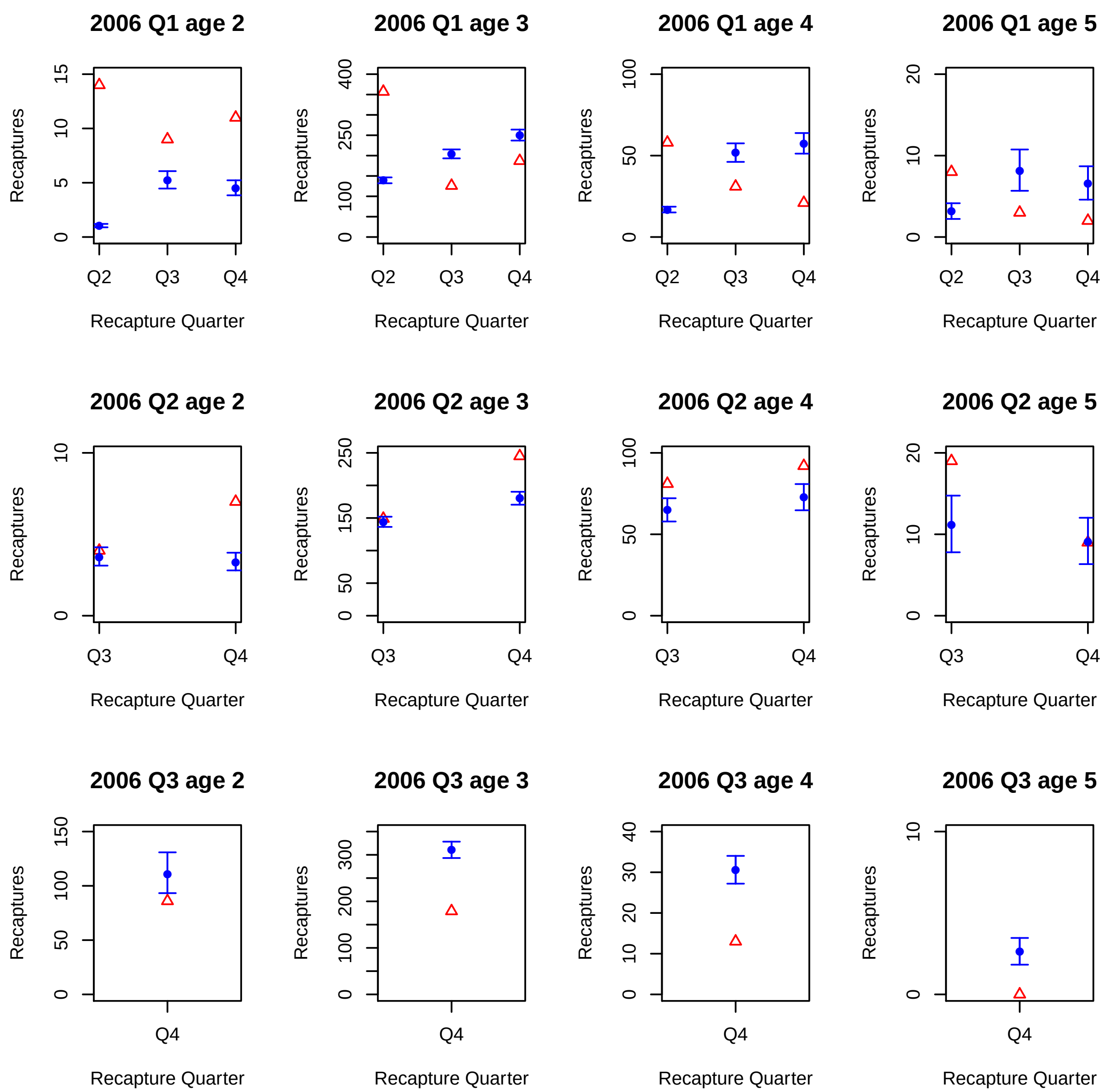

Figure 7: **Option 1**. Fits to the tag recapture events by release event and age for 2006. Red triangles denote the observed recaptures and the blue circles and bars represent the median and 95% credible interval for the model-predicted recaptures

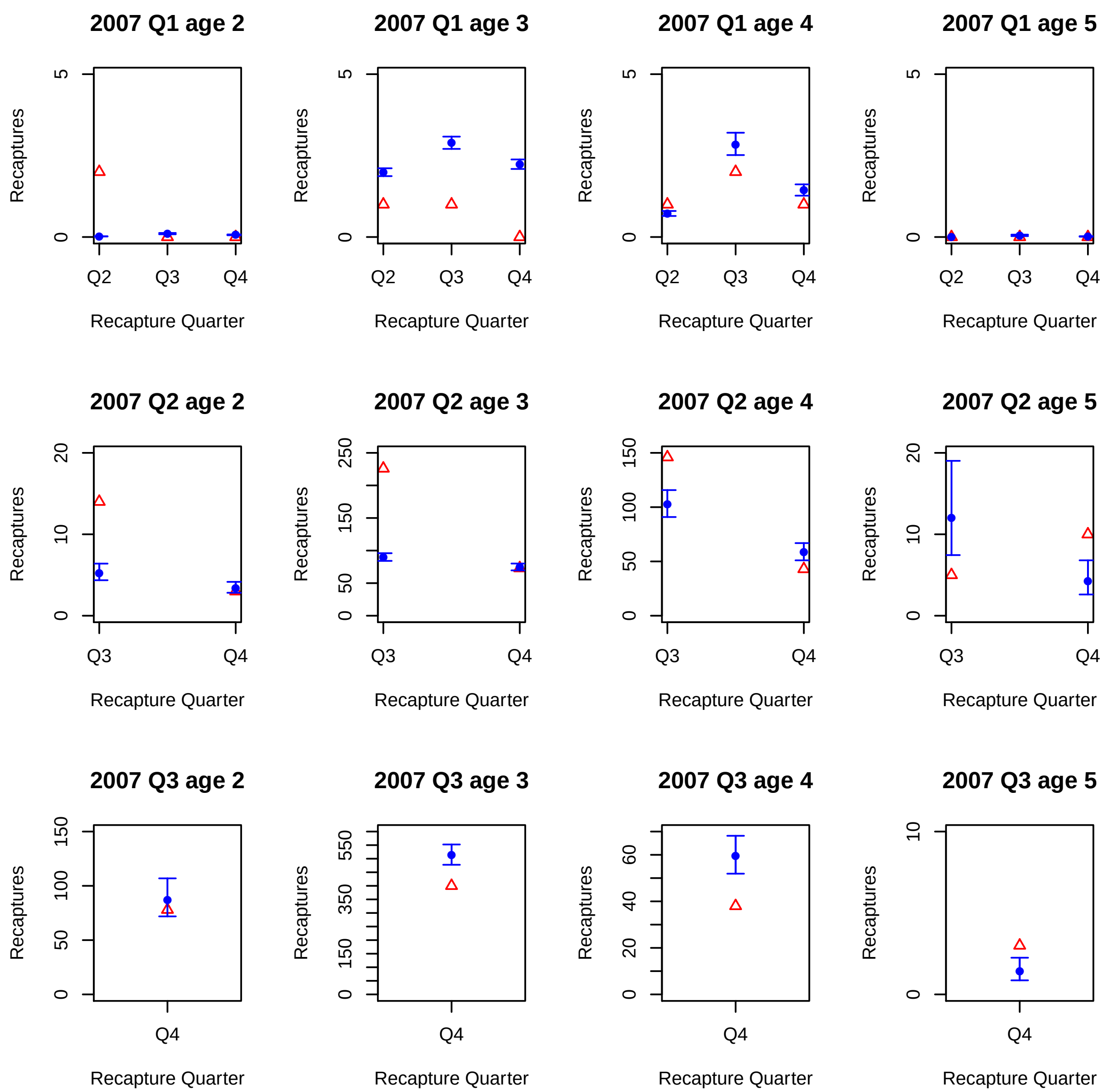

Figure 8: **Option 1**. Fits to the tag recapture events by release event and age for 2007. Red triangles denote the observed recaptures and the blue circles and bars represent the median and 95% credible interval for the model-predicted recaptures

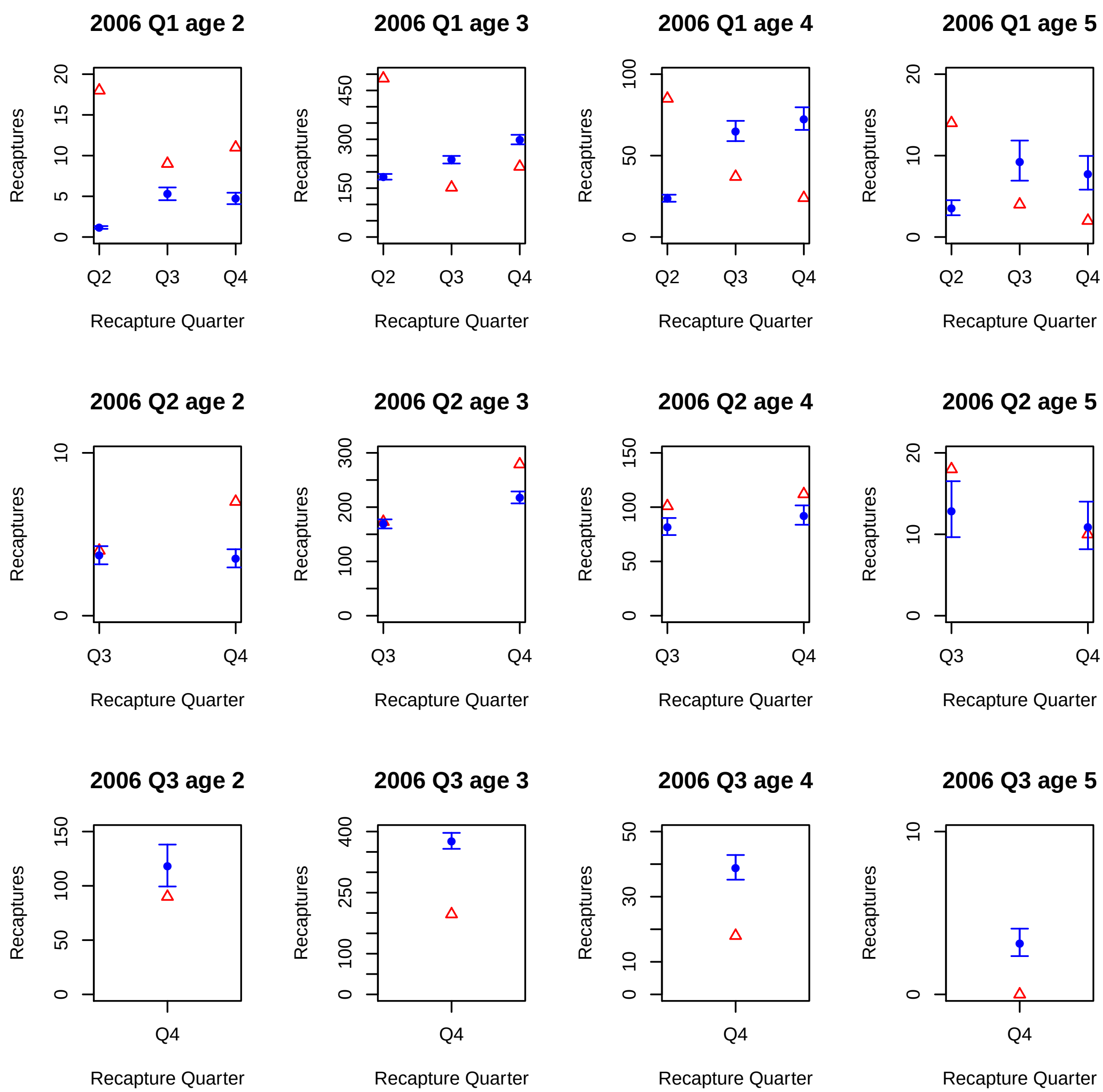

Figure 9: **Option 3**. Fits to the tag recapture events by release event and age for 2006. Red triangles denote the observed recaptures and the blue circles and bars represent the median and 95% credible interval for the model-predicted recaptures

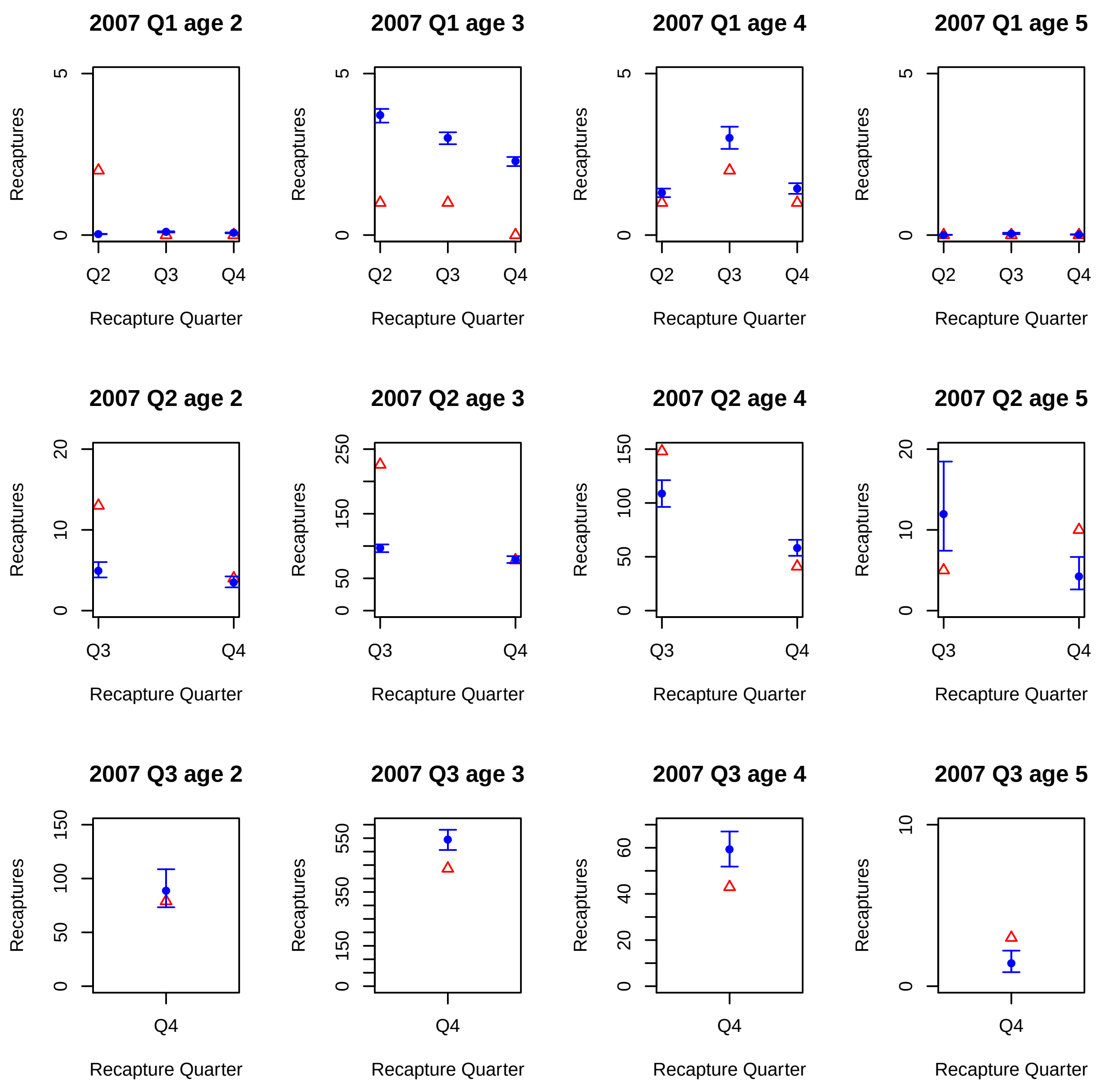

Figure 10: **Option 3**. Fits to the tag recapture events by release event and age for 2007. Red triangles denote the observed recaptures and the blue circles and bars represent the median and 95% credible interval for the model-predicted recaptures