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ANALYSIS OF TAGGING DATA FROM NORTH ATLANTIC ALBACORE (*THUNNUS ALALUNGA*): ATTRITION RATE ESTIMATES

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SUMMARY

In this study, an attempt is made to estimate natural mortality rate for North Atlantic albacore. We implement a spatially aggregated tag-attrition model to analyse the results of an albacore tagging experiment conducted in the Bay of Biscay from 1988 to 1991. The model predicts probabilities of the possible fates of tagged fish and the tags that they carry. The model includes several parameters consisting of catchabilities by fleets involved in recaptures and a combination of natural mortality plus emigration from the study area. Model fitting is carried out by finding the maximum of a multinomial likelihood function. Effect of reporting rate values on the estimations are evaluated and several hypothesis on the pre-mixing period of the tagged fish population among the total albacore population are made. Depending on model formulations selected, attrition rate of 0.56 and 0.84 per year are estimated. Although those estimates are reasonably consistent with previous studies, several uncertainties still limit our interpretation of the results in terms of natural mortality rate.

RÉSUMÉ

La présente étude tente d'estimer le taux de mortalité naturelle du germon nord-atlantique. Nous appliquons un modèle d'attrition des marques agrégé dans l'espace pour analyser les résultats d'une expérience de marquage de germon menée dans le golfe de Gascogne de 1988 à 1991. Le modèle prédit la probabilité du destin éventuel du poisson marqué et de la marque dont il est porteur. Le modèle comprend plusieurs paramètres qui consistent de la capturabilité des flottes concernées par les recaptures et d'une combinaison de la mortalité naturelle et de l'émigration hors de la zone sous étude. L'ajustement du modèle est effectué en recherchant la valeur maximale d'une fonction plurinomiale de probabilité. L'impact des valeurs du taux de déclaration sur les estimations est évalué, et plusieurs hypothèses sont avancées sur la période antérieure aux échanges de la population de poissons marqués par rapport à l'ensemble de la population de germon. Selon les formules modéliques retenues, un taux d'attrition de 0.56 et 0.84 par an est estimé. Bien que ces estimations concordent de façon raisonnable avec les études antérieures, plusieurs incertitudes limitent encore notre interprétation des résultats en termes du taux de mortalité naturelle.

RESUMEN

En este estudio, se intenta estimar la tasa de mortalidad natural del atún blanco del Atlántico Norte. Hemos aplicado un modelo de tasa de pérdida de marcas agregado espacialmente para analizar los resultados de un experimento de marcado de atún blanco realizado en la Golfo de Vizcaya desde 1988 a 1991. El modelo predice probabilidades de posibles destinos de los peces marcados y de las marcas que éstos llevan. El modelo incluye varios parámetros compuestos por la capturabilidad de las flotas implicadas en las recapturas y una combinación de mortalidad natural más emigración de la zona estudiada. El ajuste del modelo se realiza averiguando el valor máximo de una función polinómica de probabilidad. Se evalúa el efecto en las estimaciones de los valores de las

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tasas de declaración de marcas y se formulan varias hipótesis sobre el período previo a la mezcla de la población de peces marcados con la población total de atún blanco. Dependiendo de las formulaciones de modelos seleccionadas, se estiman unas tasas de pérdida de marcas de 0,56 y 0,84 por año. Aunque estas estimaciones coinciden con anteriores estudios, las incertidumbres siguen limitando nuestra interpretación de los resultados en términos de tasa natural de mortalidad.

KEY WORDS

Albacore, Tagging, Natural mortality, North Atlantic

INTRODUCTION

Albacore (*Thunnus alalunga*) tagging programs were carried out by several scientists and institutions in the north Atlantic in the seventies, eighties and nineties to provide information on migratory patterns, stock structure and estimate biological parameters such as growth and mortality.

Migratory movements of young and adult albacore in the north Atlantic were thus first described by Aloncle and Delaporte (1973; 1979). Their hypothesis on albacore movements were later confirmed by Bard (1981) from further tagging data collected in the following years. Data collected in the 80´s and 90´s lead to the same conclusion and permitted to give support to the assumed stock structure for albacore in the Atlantic ocean (Ortiz de Zárate and Cort, 1998). Models that incorporate individual variation on growth were also fitted to the tagging data to estimate growth parameters of north stock albacore (Ortiz de Zárate and Restrepo, 2001).

While natural mortality play a key role in stock assessment and only arbitrary value (M=0.3) based on estimates derived from the Pauly´s method (Pauly, 1980) and the 5% Rule (Anonymous, 1990) has been used during the SCRS assessment sessions since 1989, the tagging data collected to date have not yet been analyzed to estimate mortality rates. In this paper, a tag-attrition model (Kleiber et al., 1987) incorporating several assumptions is fitted to the albacore tagging data and estimates of attrition rate (natural mortality plus emigration) and fleet-specific catchability coefficients are obtained. Those estimates are discussed and recommendations for future tagging experiments are made.

MATERIALS AND METHODS

Tagging data

The tagging data used in this analysis are those obtained from the IEO data base which are reported and compiled in the ICCAT database from 1988 to 1998. Scientists of IEO have been involved in tagging tuna campaigns since 1976. Before 1988 some tagging experiments were developed by this Institute with the use of troll commercial vessels and recreational vessels with rod and reel, on opportunistic bases during bluefin tagging campaigns (Cort and Mejuto, 1990) and the small scale experiences carried out with troll commercial vessels during 1983 and 1985 (Mejuto, 1984; 1985). The total number of tagged albacore in those years reached 1032 and most of the recaptures took place during the same year of release.

From 1988 to 1991 the tagging campaigns on albacore were carried out using a commercial troll vessel in 1988 and a commercial baitboat vessel from 1989 onwards within the frame work of the International Albacore Special Program (Anonymous, 1996). The use of a baitboat commercial vessel brought a substantial increase on the release number of tagged albacore from the first experience (Ortiz de Zárate *et al.*,1991). From 1988 to 1991, a total of 12332 tagged albacore were released mainly during the month of August with some even extension to September and October. The tagging methods applied were based on use of conventional tags, type dart, on board commercial fishing vessels. Tagged albacore were mainly released during the peak of the fishing season over a limited area (Cort *et al.* 1992) situated in the south of the Bay of Biscay (Figure 1). Their size distribution is dominated by 50 to 60 cm fork length fish (1 year old) which represent more than 80 % of total tagged albacore (Figure 2).

A total of eligible 409 tagged albacore (3.3 % of the releases) have been recaptured to date from the experiences that took place from 1988 to 1992 and have been analysed in this study. The recaptures have been recorded from several national fleets and gear types but the largest numbers of recaptures were made by bait-boats and troll boats from Spain, drift-nets and mid-water trawlers from France (Table 1). Except for one recovery made in the western Atlantic by a US mid-water trawler, recaptures occurred essentially in the north-eastern Atlantic, reflecting the spatial distribution of surface fleets (Figure 3a-e). One more recapture was reported in 1998, however no information on location, size and gear being available, it was thus not considered in the analyses.

Description of the tag-attrition model

The model used for this analysis is a tag-attrition model (e.g., Seber, 1973; Kleiber *et al.*, 1987). It describes the dynamics of tagged albacore and the decline in rate of tags recapture as the population of tagged fish at large declines with time following release. This decline occurs mainly because of natural mortality, emigration out of the study area and fishing mortality. The model may be represented by:

$$\hat{r}_{ijf} = R_i(1-a)b\exp\left[-\sum_{k=1}^{j-1}\sum_f (F_{ikf}) - (j-1)(A+y)\right] \frac{F_{ijf}}{\sum_f F_{ijf}+A+y}\left[1-\exp(-F_{ijf}-A-y)\right] \qquad (1)$$

where $\hat{r}_{ijf}$ is the estimated number of tags from release group i recaptured by fleet f in time period j and returned with complete information (recapture time and fleet), R_i is the number of tags released in release group i, a is the proportion of type-1 tag losses, b is the proportion of recaptured tags that are returned, F_{ijf} is the instantaneous rate of fishing mortality on release group i in time period j by fleet f, A is the sum of instantaneous rate of natural mortality and permanent emigration from the study area (assumed constant over time and referred to as attrition rate), y is the instantaneous rate of type-2 tag loss, i is an index for release group, j is an index for time period, k is an index for time periods prior to j; and f is an index for fleet.

Data stratification

Tag releases were grouped by month and year in which they were released. The structure of the analytical model is such that tagged fish are assumed to be released at the start of a given calendar month. To make the observed data correspond to that scenario as closely as possible, the release data were aggregated into release sets by rounding the date of release to the nearest first-of-the-month. Thus the releases for a given month include release dates between the fifteenth of the previous month and the fifteenth of the given month, resulting in 13 release groups (Table 2). The returns were aggregated by month by truncating the recapture date to month. Thus, the recoveries assigned to a given month are those with recapture dates any time within that month. Again, this corresponds to the structure of the analytical model, which predicts the number of returns within each whole month following the release date. On some occasions with the above scheme, tags released in the last half of a month would be recaptured in that same month, which would result in these recoveries being assigned a recapture one month before the assigned release month. Recoveries such as these were reassigned to the following month. We defined five fleets for recoveries: (1) Spanish bait-boat, (2) Spanish troll, (3) French troll, (4) French drift-net (5) French Mid-water Trawl. Tag returns by “other” fleets (4 recaptures) for which no fishing effort information is available were excluded from the analysis (in fact contributed to non-reporting). The observed tag returns, r_{ijf} , were thus grouped by tag release group (*i*), month and year of recapture (*j*), and recapture fleet (*f*). Tag returns to the end of 1996 were considered in the analysis.

Nuisance parameters

We have to assume values for $(1-a)b$ as those parameters cannot be estimated accurately from the data. We assumed that tag shedding was the only source of type-1 and type-2 tag loss and therefore used values for a and y of 0.10 and 0.0245 quarter^{-1}, respectively, based on analysis of double-tagging data made in the North Pacific (Laurs *et al.*, 1976). There are no independent estimates of non-reporting of North Atlantic albacore tags, so we assumed that non-reporting was “moderate” at 20% (b = 0.8). We tested the sensitivity of our results to values of b in the range 0.1 to 1.0.

Re-parameterization of fishing mortality

To create sufficient degrees of freedom to facilitate statistical estimation of parameters, the number of fishing mortality parameters to be estimated, F_{ijf} was reduced. Assuming that F_{ijf} is independent of release group i, $F_{.jf}$ may be re-parameterized as a function of fishing effort, E_{jf} , and catchability, q_f :

$$F_{.jf} = q_f E_{jf} . \tag{2}$$

Catchability by fleet is assumed to be constant over time. Monthly effort statistics for the Spanish fleets involved in the tag-recoveries were obtained from the ICCAT database while statistics for French fleets were compiled from the French CRTS (Centre Régional de Traitement Statistique) databases. Effort data were compiled for the period August 1988 to December 1996 which corresponds to the tagging experiment.

Incomplete mixing of newly tagged animals

It is often the case that recovery data in the initial months following tagging can be quite aberrant because the tagged fish have not had a chance to mix sufficiently with the non-tagged population. In our case, because most releases occurred in the south of the Bay of Biscay (Figure 1), the tagged population would have been initially more available to the Spanish bait-boat, troll and French mid-water trawl fleets and less available to the French driftnet and troll fleets, which have a more north-westerly distribution (Figure 3a-e). To address this “problem”, several approaches can be used. Hoenig et al. (1998) estimated additional fishing mortality parameters for the pre-mixing periods. Bertignac et al. (1999) added an “availability” parameter to their tag-attrition model. We chose for this study a more simple procedure by setting $\hat{r}_{i,j,f} = r_{i,j,f}$ for each of the pre-mixing period and estimating the corresponding fishing mortality coefficients by a forward solution to the equivalent of equation 1 using the Newton-Raphson algortithm (Kleiber et al., 1987; Hampton, 2000).

Parameter estimation

We used a multinomial likelihood function to fit the various models to the tagging data. A derivation of the likelihood function as applied to tagging data is given in Kleiber and Hampton (1994). We minimized the negative log of this function to obtain the parameter estimates, i.e. minimize

$$-\sum_i \left[\left(R_i - \sum\nolimits_k r_{ik} \right) \ln\left(1 - \frac{\sum\nolimits_k \hat{r}_{ik}}{R_i} \right) + \sum\nolimits_k r_{ik} \ln\left(\frac{\hat{r}_{ik}}{R_i} \right) \right] \tag{3}$$

where the k subscript here indicates an individual recapture stratum (combining recapture period, fleet, and time at liberty dimensions). Minimization was carried out using a quasi-Newton routine (Otter Research, 1991). The variance-covariance matrix of the estimated parameters was estimated from the inverse of the Hessian matrix (Bard, 1974).

RESULTS

Model fits

Two slightly different models were fitted to the North Atlantic albacore tagging data. Model 1 has no pre-mixing period. For model 2, likelihood ratio tests was used to choose the optimal number of premixing periods for each data set as suggested by Hoenig et al. (1998) and Hampton (2000). This model, which includes 3 months mixing time was the one with the smallest number of periods for which the P value of the χ^2 test for adding a premixing period was > 0.05 (Table 3). Plots of observed and predicted tag returns, aggregated over tag release groups, are shown in Figure 4 for model 1 and in Figure 5 for model 2. As expected, there are discrepancies between observed and predicted returns for model 1, particularly in the time periods soon after release while for model 2, the predicted recoveries for pre-mixing period equal the observations.

Parameter estimates

The results of the models are given in Tables 4 and 5. Although high (0.59 or 0.84 depending on which model formulation is used), estimates of attrition rate A, comprising natural mortality and permanent movement away from the area fished by surface fishery, are reasonably consistent with previous estimates of M for Pacific albacore (Fournier et al., 1998, Bertignac et al., 1999). Model 1 estimates of A and fishing mortality are lower because in this fit, the model attempts to accommodate the low numbers of initial tag returns by decreasing the value of these parameters.

Effect of assumed tag reporting rate

We examined the sensitivity of the results to different values of b (assumed to apply equally to each fleet) for the model 1 fit. The estimates of A are directly related to b (Figure 6). The sensitivity is slight for $b > 0.5$. If the tag-reporting rate was above this level for the main fleets, the results of our analysis should be robust to small departures from the assumed value. In the absence of other information, the tag-reporting rate has been assumed constant over time.

DISCUSSION

The natural mortality rate is difficult to estimate accurately and is a major source of uncertainty in fish stock assessments. In this study, an attempt was made to estimate M using a tag-attrition model. Although parameter estimates obtained are reasonably consistent with previous studies, several uncertainties still limit our interpretation of the results:

1. The use of a tagged sample of the population to infer characteristics of the population in general requires several assumptions, discussed in detail by Seber (1973). For North Atlantic albacore, the assumption of equal probabilities of capture of tagged and untagged fish is likely to be critical. As noted earlier, the spatial distribution of the tagged population in relation to recapture effort are likely to result in violation of this assumption. We tried to correct for these deficiencies in an approximate way. A more elegant approach would be to develop a model that explicitly deals with the spatial structure of the tagged population and the spatial distribution of fishing effort. Such spatially-disaggregated tag models are now available (e.g., Kleiber and Hampton, 1994; Sibert et al., 1999).

2. Another limitation of our analysis is the size of the study area, limited to the surface fishery, as compared to the whole distribution area of the stock in the North Atlantic. Emigration out of this area is thus part of the attrition rate estimated by our model. Although it could be quite significant, it cannot be estimated with the present dataset.

3. To this uncertainty over emigration and thus over natural mortality can be added the one linked to the size distribution of tagged fish in relation with the size-selectivity characteristics of recapture gears. As shown earlier, more than 80% of the tagged fish were from similar size, mainly in the 50 to 60 cm size range. In such a case and as a first approximation, we can assume that the selectivity of the surface gears would vary in relation with time at liberty. As the tagged fish grew out of the size range typically exploited by those fisheries, their "availability" would decrease. This decreasing trend is thus part of the attrition process estimated by the model and should also be removed from our estimates of attrition rate. As for emigration mentioned above, it is however not possible, with the present data, to tell what proportion of attrition it represents.

Due to these uncertainties, there is no ground for changing the value of *M* presently used by SCRS. However, these preliminary results permit the formulation of some recommendations in case of future tagging experiments. Tagging just at (or after) the end of the fishing season would give enough time for tagged fish to mix with the untagged population. Tagging in a larger area would also help to partially solve the problem of relative spatial distribution of tagging and fishing effort by fleet in case a spatially-aggregated tag attrition model were used. Finally, emphasis should be put on the return rate from the longline fleets (for instance through publicity), as this should permit, if tagged fish are recovered and returned by those fleet, to reduce the uncertainty on *M* linked to emigration out of the study area.

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Table 1. Number of albacore tag returns in the north-east Atlantic, 1988-1998, by recapture fleet.

Gear type	Nationality	Number of returns	%
Bait-boat	Spain	279	68.22
Troll	Spain	55	13.45
Troll	France	4	0.98
Drift-net	France	30	7.33
Mid-water trawl	France	37	9.05
Other		4	0.98
Total		409	100.00

Table 2. North Atlantic albacore tag release and return data, summarized by release group.

Releases			Returns					
Group	Date (month/yr)	Number	Spanish Bait-Boat	Spanish Troll	French Troll	French Driftnet	French MW trawl	Total
1	8/1988	65	4	0	0	0	0	4
2	9/1988	134	12	0	0	0	0	12
3	10/1988	258	18	0	0	1	1	20
4	11/1988	32	3	0	0	0	0	3
5	9/1989	2718	62	12	1	3	10	88
6	10/1989	272	4	2	0	1	2	9
7	12/1989	20	0	0	0	0	0	0
8	8/1990	110	1	0	0	0	0	1
9	9/1990	4314	67	12	1	6	4	90
10	10/1990	150	1	0	0	0	1	2
11	8/1991	675	28	9	1	2	5	45
12	9/1991	3583	79	20	1	17	14	131
13	10/1991	1	0	0	0	0	0	0
Total		12332	279	55	4	30	37	405

Table 3. Statistical test to select the number of premixing periods. (selected model based on a critical value of P = 0.05 is boldfaced)

Number of mixing periods	Number of parameters	χ^2	*P*
1	19	137.88	<0.001
2	32	131.46	<0.001
3	**45**	**37.68**	**<0.001**
4	58	7.92	0.84
5	71	0.02	0.99

Table 4. Parameter estimates (and CV) obtained from fits to the North Atlantic albacore tagging data.

Models	*A*	Catchability coefficients					Negative log-likelihood
		Spanish Bait-boat	Spanish troll	French Troll	French Drift-net	French MW Trawl	
1	0.59 (0.08)	3.72E-06 (0.08)	3.87E-07 (0.14)	6.57E-08 (0.50)	1.35E-07 (0.20)	3.00E-07 (0.17)	3119.88
2	0.84 (0.09)	6.31E-06 (0.13)	5.53E-07 (0.20)	1.64E-07 (0.51)	2.53E-07 (0.22)	5.57E-07 (0.24)	2966.37

Table 5. Correlation matrix for parameters (model 1 fit).

		A	Catchability coefficients			
			Spanish Bait-boat	Spanish troll	French Troll	French Drift-net
Catchability	Spanish Bait-boat	0.595				
	Spanish troll	0.309	0.195			
	French Troll	0.069	0.044	0.023		
	French Drift-net	0.299	0.188	0.098	0.022	
	French MW Trawl	0.258	0.163	0.085	0.019	0.082

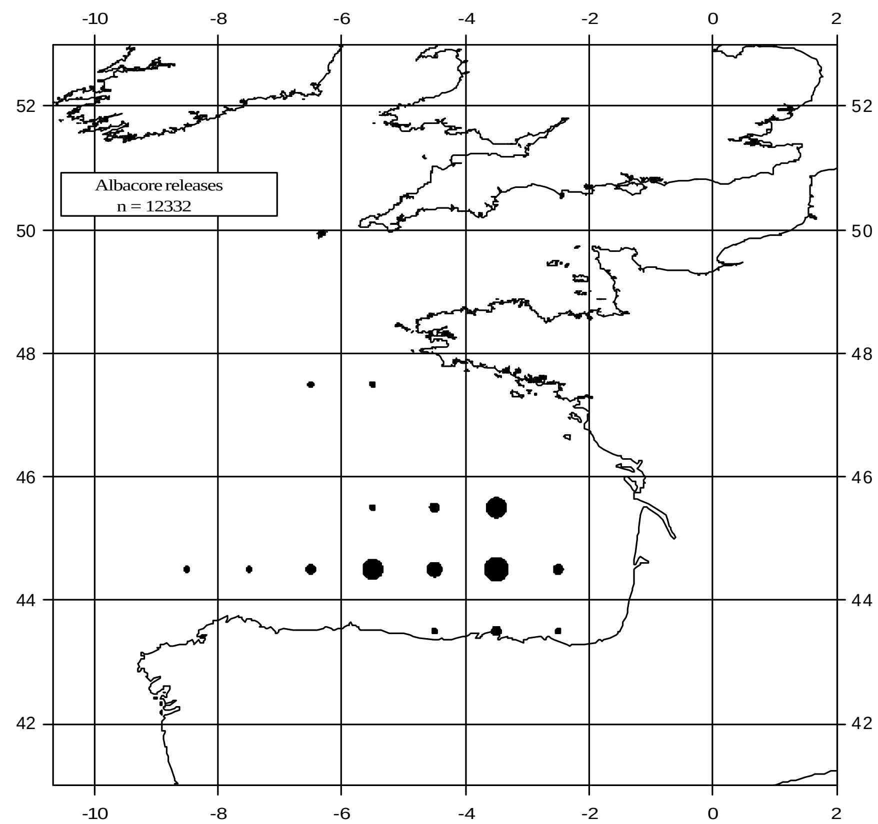

Figure 1. Geographical distribution of North Atlantic albacore releases (1988-1991).

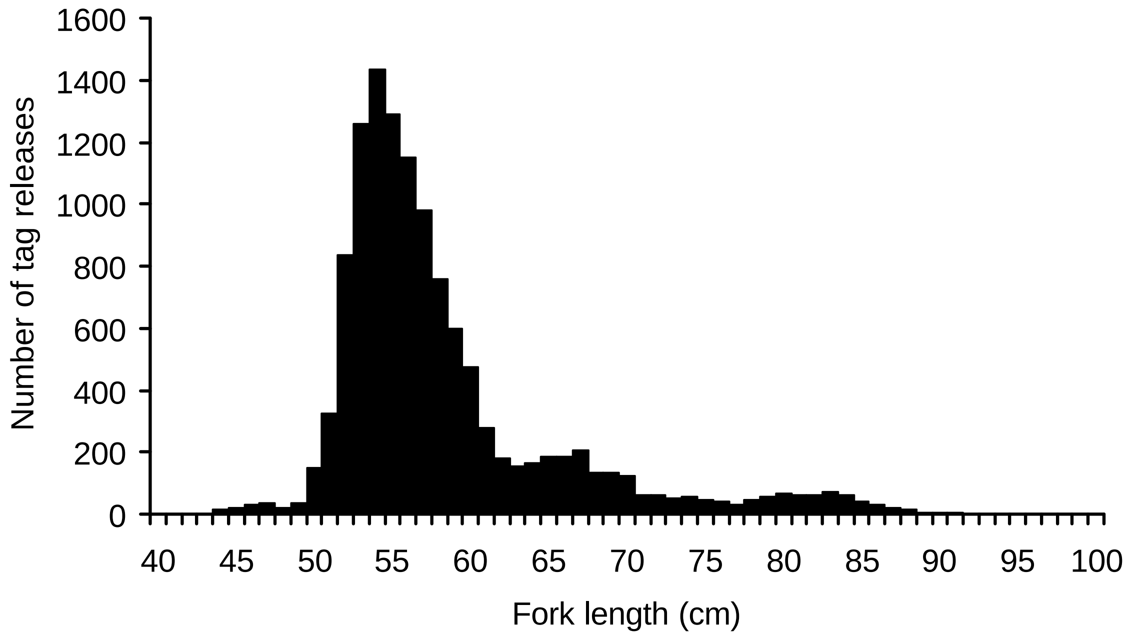

Figure 2. Size distribution of North Atlantic albacore tag releases, 1988-1991.

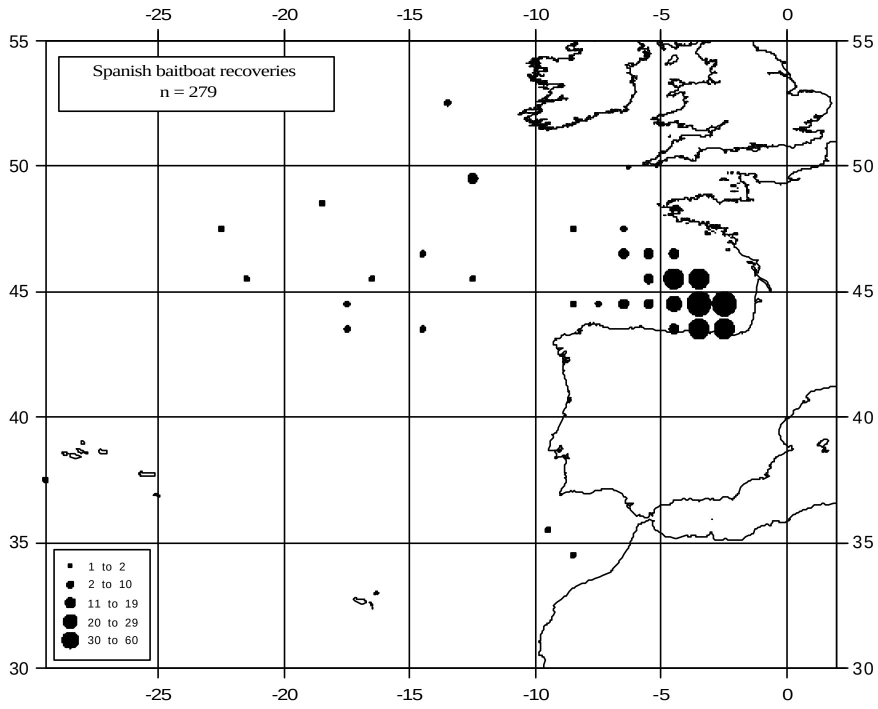

Figure 3a. Geographical distribution of North Atlantic albacore recoveries made by Spanish bait-boats 1988-1996.

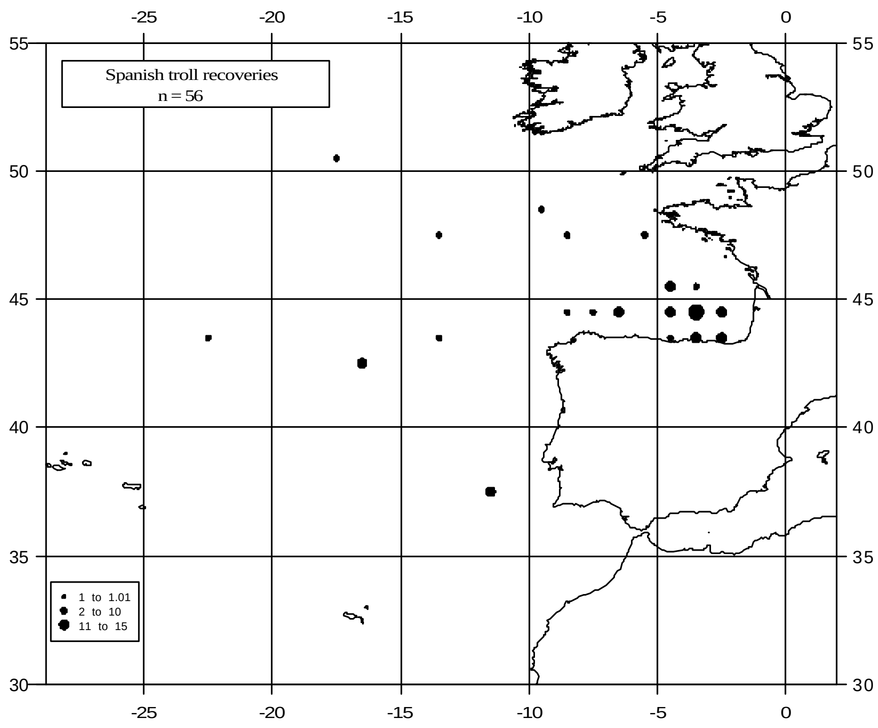

Figure 3b. Geographical distribution of North Atlantic albacore recoveries made by Spanish troll 1988-1996.

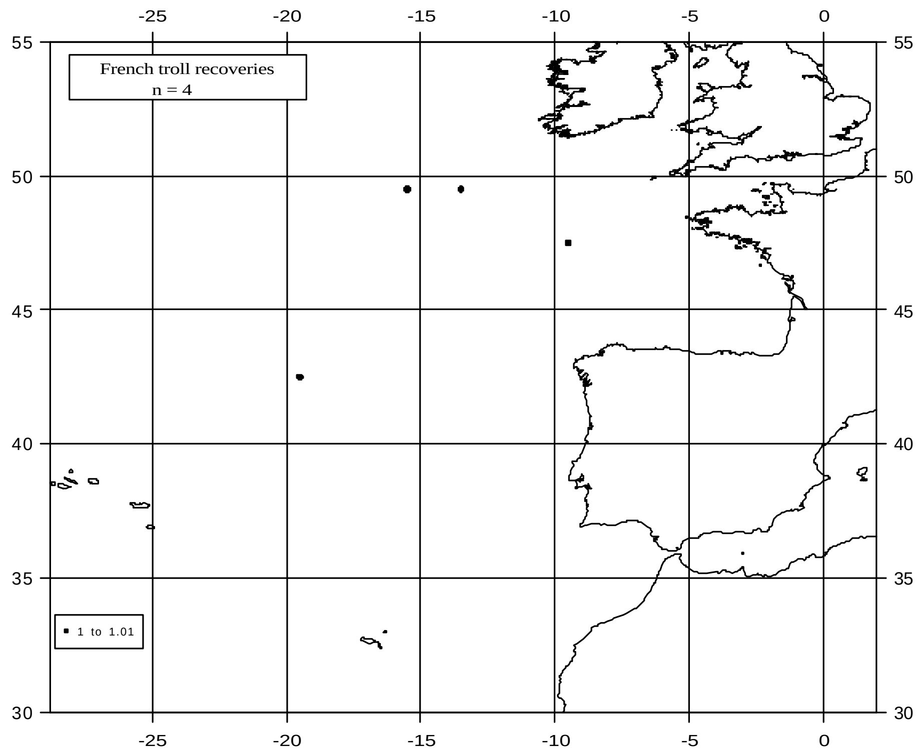

Figure 3c. Geographical distribution of North Atlantic albacore recoveries made by French troll 1988-1996.

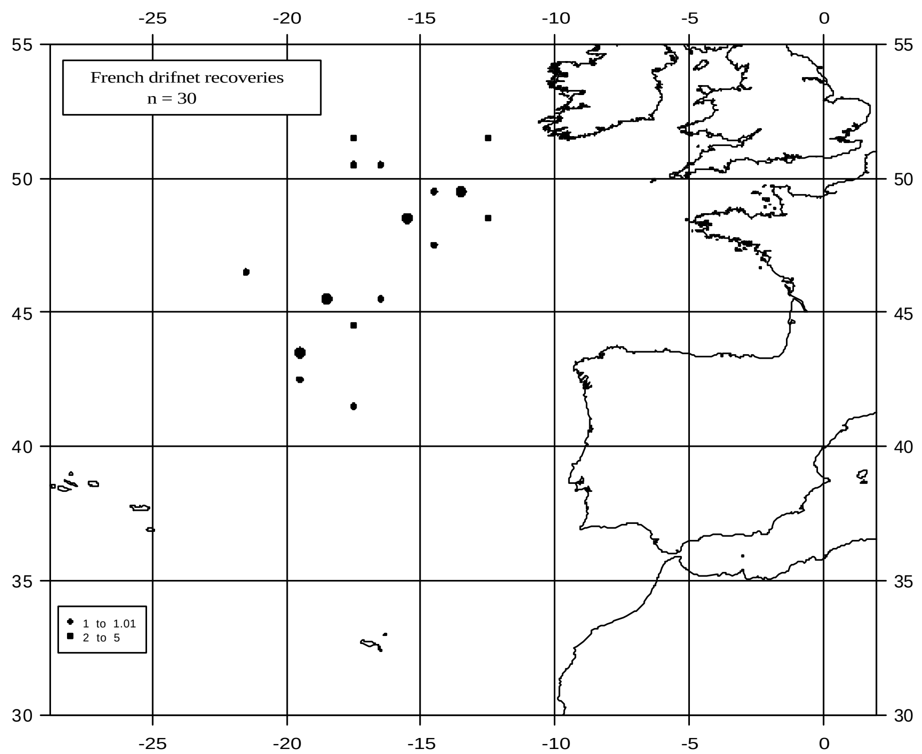

Figure 3d. Geographical distribution of North Atlantic albacore recoveries made by French Driftnets 1988-1996.

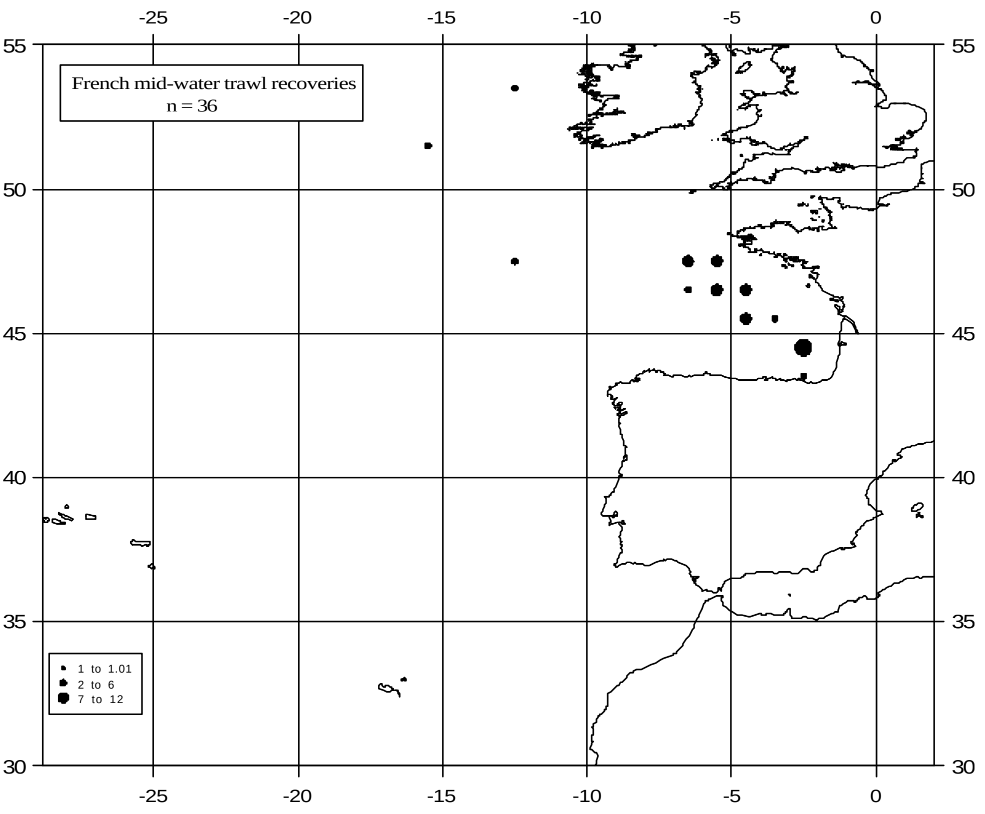

Figure 3e. Geographical distribution of North Atlantic albacore recoveries made by French Mid-water trawlers 1988-1996.

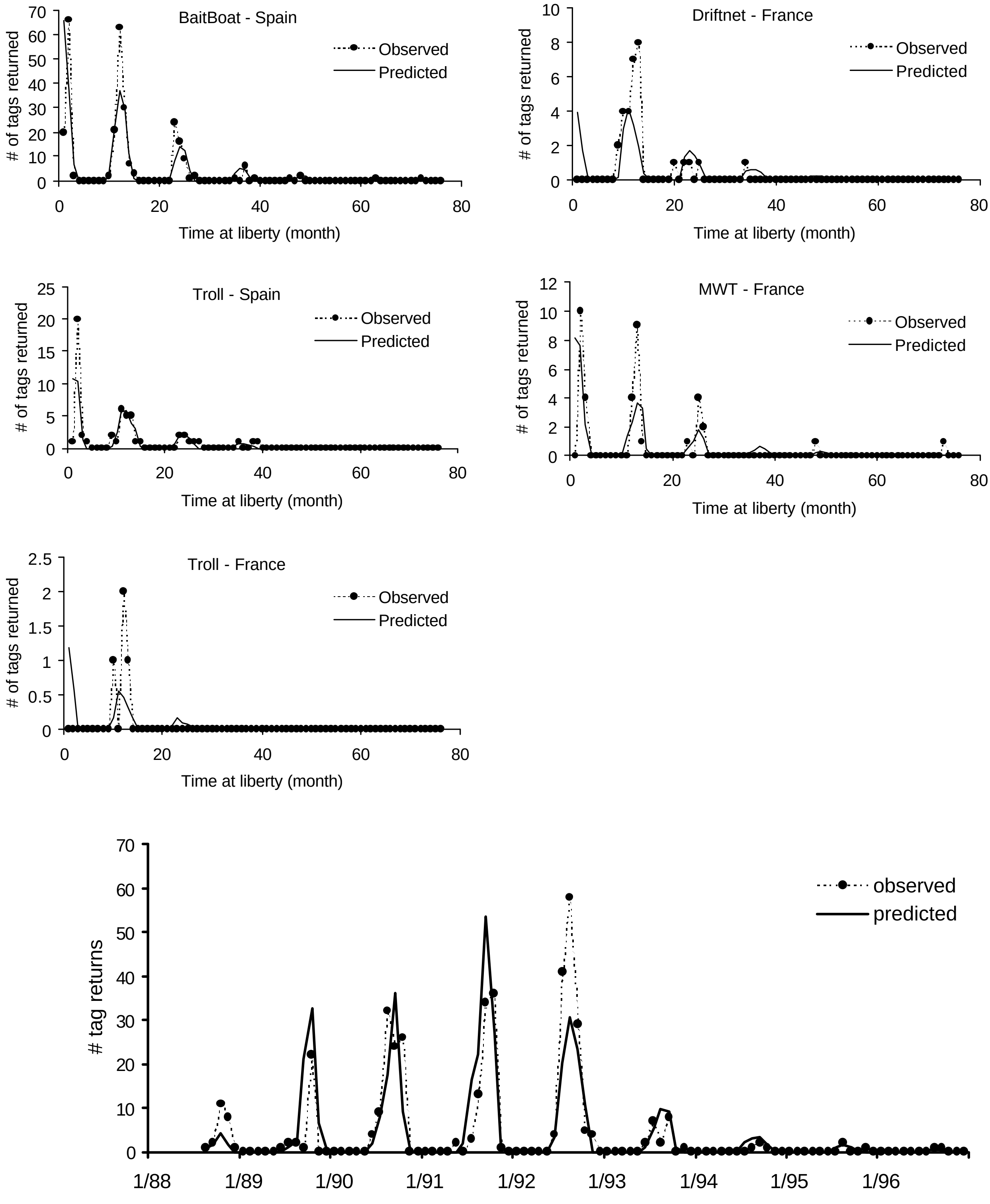

Figure 4. Observed tag return numbers and tag returns predicted using model 1.

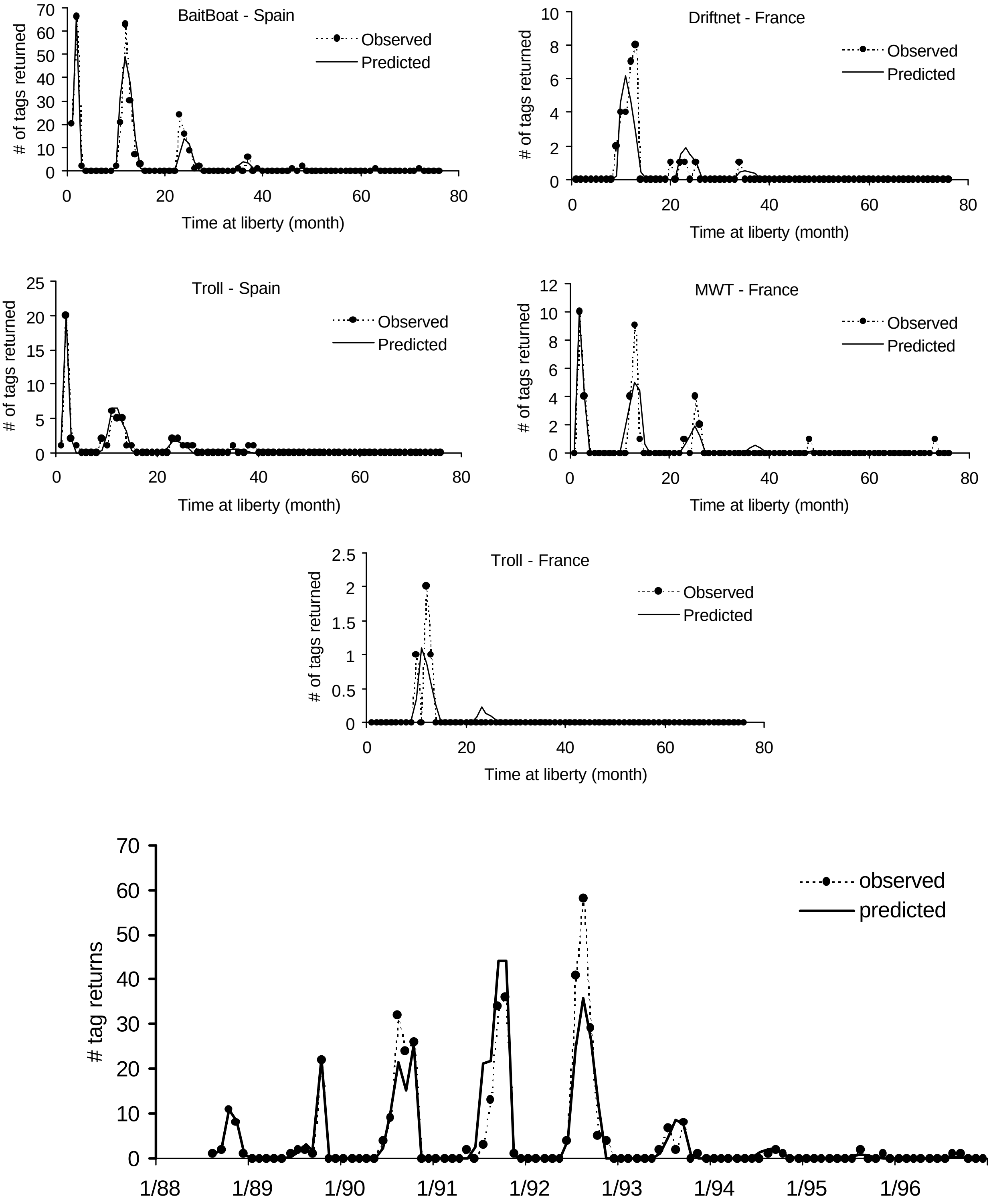

Figure 5. Observed tag return numbers and tag returns predicted using model 2.

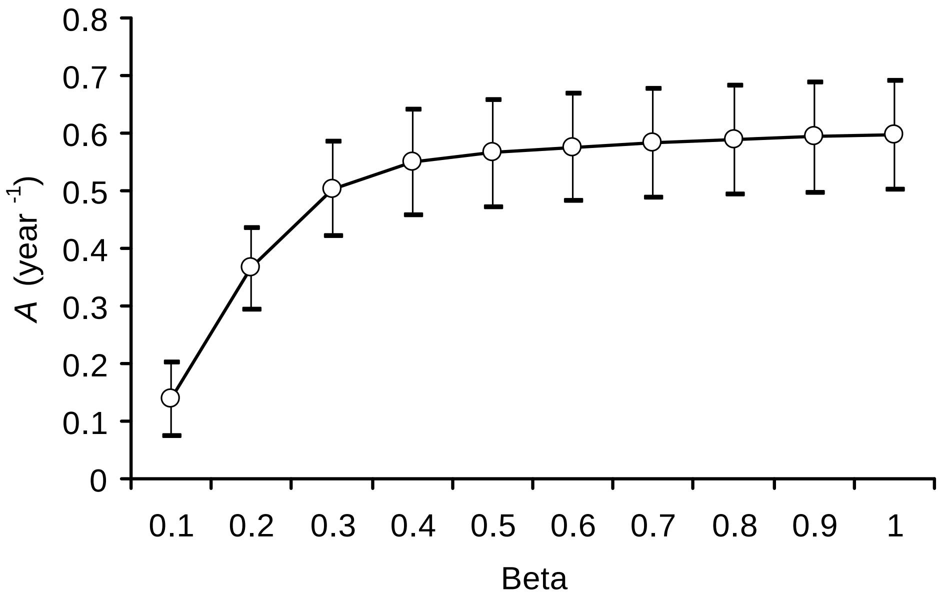

Figure 6. Estimates of annual attrition rate (and 95% confidence limits) for model 1 as a function of the tag-reporting rate (*b*). The same value of *b* is assumed to apply to each fleet.