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Exploitation rates and population size of cod in Placentia Bay (Subdivision 3Ps): estimates from a new mark-recapture study.

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Abstract

Approximately 6,000 commercial sized (>40 cm) cod were tagged with t-bar anchor tags and released at various locations in Placentia Bay and adjacent areas prior to and during the 1997 commercial fishery. The tagging program and associated reward scheme were advertised widely among those participating in the fishery. Cod were tagged with one yellow ($10 reward), two yellow ($20 reward for both), or one pink tag ($100 reward) in approximate proportions 0.45:0.45:0.1. The high-reward tags were used to estimate the reporting rate of standard ($10 reward) tags; double tags were applied to investigate the rate of long-term tag loss. Experiments involving retention of tagged cod in submersible enclosures were conducted to provide estimates of initial tag shedding and short-term tagging mortality. Exploitation rates were estimated for each stock component that was tagged; the estimates were based on numbers of single-tagged cod reported as recaptured during the fishery, adjusted to account for reporting rate, natural mortality, and various sources of tag loss and tagging mortality. Estimates of exploitation rate on inshore spawning aggregations tagged before the fishery began averaged 0.170 and ranged from 0.126 to 0.213; the corresponding estimate for a large spawning aggregation tagged 5 - 9 days after the fishery began was 0.078. The 1997 commercial fishery consisted mainly of three short periods of fishing activity. A model that used information on tag returns and commercial catch was developed to provide estimates of the overall exploitation rate associated with each period of fishing and to back-calculate a population size for cod in Placentia Bay prior to reopening of the commercial fishery. The model assumed a closed population from April-October, and constant exploitation rates throughout Placentia Bay. The model gave estimated exploitation rates of 0.042, 0.041 and 0.023 for the first, second, and third periods of fishing. Initial population size was estimated at about 26 million fish, or approximately 52,000 mT based on an average commercial weight of 2.0 kg per fish from the commercial catch.

Résumé

On a apposé des marques à ancrage en T chez environ 6 000 morues de taille commerciale (>40 cm) qui ont ensuite été relâchées à différents endroits dans la baie Placentia et les zones adjacentes avant et pendant la saison de pêche commerciale de 1997. Le programme de marquage et le programme de prime à la récupération ont été annoncés aux participants à cette pêche. Les morues ont été marquées au moyen d'une marque jaune (prime de 10 $), de deux marques jaunes (prime de 20 $ pour les deux), ou d'une marque rose (prime de 100 $) dans les proportions approximatives suivantes : 0,45:0,45:0,1. Les marques à prime élevée ont été utilisées pour évaluer le taux de déclaration des marques standard (10 $); des marques doubles ont été apposées pour étudier le taux de perte des marques à long terme. Des expériences ont été menées sur des morues marquées retenues dans des enceintes submersibles afin d'évaluer la perte initiale des marques et la mortalité due aux marques à court terme. On a évalué le taux d'exploitation de chaque composante du stock marqué; les estimations étaient fondées sur le nombre de morues portant une seule marque et qui ont été déclarées comme recaptures pendant la saison de pêche, corrigé pour tenir compte du taux de déclaration, de la mortalité naturelle et des différentes sources de perte de marques et de la mortalité due aux marques. Les estimations du taux d'exploitation des agrégations côtières de géniteurs marqués avant le début de la saison de pêche s'établissaient en moyenne à 0,170 et variaient entre 0,126 et 0,213; l'estimation correspondante pour une grande agrégation de géniteurs marqués entre 5 et 9 jours après l'ouverture de la pêche était de 0,078.

La pêche commerciale de 1997 a consisté principalement en trois courtes périodes de pêche. On a élaboré un modèle à partir des données figurant sur les marques retournées et des prises commerciales afin d'évaluer le taux d'exploitation général associé à chaque période de pêche et d'effectuer le rétrocalcul de la taille de la population de morue de la baie Placentia avant la réouverture de la pêche commerciale. Selon le modèle, la population était fermée d'avril à octobre, et les taux d'exploitation constants dans la baie Placentia. Le modèle donnait des taux d'exploitation estimés de 0,042, 0,041 et 0,023 pour la première, la deuxième et la troisième période de pêche. La taille initiale de la population a été évaluée à environ 26 millions de poissons, soit environ 52 000 tonnes métriques d'après un poids commercial moyen de 2,0 kg par poisson.

1 Introduction

Several mark-recapture (tagging) experiments have been conducted on cod off the south coast of Newfoundland and the information from recaptures has been used mainly to investigate cod movement patterns and stock structure (Lear 1984, 1988; Moguedet 1994; Templeman 1974, 1979; Taggart et al. 1995). However, with a well-designed multi-year tagging study it is also possible to estimate several other parameters of interest to fisheries managers, including exploitation rates and survival rates. Estimates of these parameters can be obtained on sub-components of the overall population. The methodology has been described in detail by Brownie et al. (1985). Recently, Myers et al. (1996, 1997) used a modification of the methodology to conduct a post-hoc analysis of cod tagging data from northeastern Newfoundland and concluded that tagging data gave strong evidence of high rates of exploitation in the late 1980's and early 1990's; however, their model requires many assumptions. As Myers and Hoenig (1997) point out, there have been no cod tagging studies specifically designed to obtain estimates of exploitation, survival, or mortality rates.

Pollock et al. (1991) reviewed the theory of tagging models and showed that for a single year tagging study it is possible to estimate exploitation rate, but not total or natural mortality. With a multi-year tagging study where tags are returned from a commercial or recreational fishery it is possible to estimate total annual survival rate. Fishery managers would also like estimates of natural mortality and fishing mortality rates and this can also be achieved from tagging data provided additional information is obtained on tag-shedding and tag-induced mortality rates, as well as tag reporting rates.

Tagging studies have provided useful information about cod movement patterns within NAFO subdivision 3Ps, but stock structure is complex and remains poorly understood. At least five stock components may contribute to the fishery in 3Ps (Brattey 1996). Cod that spend the summer in the western and northern Gulf migrate out of the Gulf and overwinter off southwestern Newfoundland. During winter, an annually variable portion of these cod appear to migrate across the 3Pn4RS stock boundary into 3Ps thereby complicating interpretation of winter RV surveys and hence assessment of these adjacent stocks (D'Amours et al. 1994; Rollet et al. 1994; Shelton et al. 1996; Campana et al. 1998). Historically, a portion of the stock components that overwintered offshore on St. Pierre Bank and adjacent areas migrated inshore in the summer and contributed to inshore catches. However, in the late 1980's and early 1990's the overall abundance of cod in the 3Ps trawl research survey region appeared to decline (Shelton et al. 1996), yet inshore of the survey region catch rates from the sentinel surveys in 1995-1997 and the commercial fishery in 1997 were high. To improve the reliability of 3Ps cod assessments, more detailed information is required on stock structure and the relationship between inshore and offshore stock components. More information is also needed on exploitation and survival rates of individual stock components.

This paper describes findings of a new mark-recapture study initiated in 1997. This study was designed to provide estimates of the exploitation rates on sub-components of the 3Ps cod stock, and in this paper we focus on the components of the stock inhabiting Placentia Bay. The study includes methods to estimate tag reporting rate, short-term tagging mortality, and short-term and long-term tag loss. We also develop a model that uses information on commercial catches and tag returns over time to estimate (1) overall exploitation rates on Placentia Bay cod associated with commercial fishing activity during 1997, and (2) population size of cod in Placentia Bay prior to the reopening of the commercial fishery in 1997.

If the fishery and tagging continue for two or more years it should also be possible to obtain estimates of survival and mortality rates for some stock components. The 3Ps cod stock had previously been under moratorium since August 1993. Information on migration patterns of cod from these tag returns is summarized elsewhere (Lawson, Rose, and Brattey 1998).

2 Materials and Methods

Most cod for tagging were captured with hand-lines equipped with 3-5 feathered hooks and a Norwegian jigger equipped with a single hook; some trap-caught and otter-trawled cod were also tagged. Live cod caught with hand-lines or otter trawls were initially placed directly into a 200 gal tank equipped with running sea water. Trap-caught fish were held at the surface, dipped from the trap catch and tagged and released immediately. The length of each cod (nearest cm) was recorded. Only cod >40 cm fork length and in excellent condition were tagged and released. Vertical cast CTD's were done at most tagging sites; at a few sites only surface temperatures from hand-held thermometers were obtained. Fish were tagged with one or two 6.3 cm t-bar anchor tags (Floy Tag Co., Seattle, Washington) inserted at the base of the first dorsal fin. Double tags were spaced approximately 3 cm apart on the same side of the fish. For analysis, groups of cod tagged in the same general area over a time frame of a few days to weeks were classified as a single experiment which was assigned a four digit sequential identifier; the first two digits representing the year of capture and the second two digits incrementing annually from 01 onwards (i.e. 9701, 9702...).

A new reward scheme was introduced to encourage those participating in the reopened fishery to return cod tags and recapture information. The reward for returning a standard tag, and any tags from previous studies, was increased from \$5 to \$10; the reward had not been increased since the early 1980's. The reward scheme was advertised widely by means of posters illustrating the size, colour, and position of attachment of tags and reward values; these were sent to all fish plants processing cod in Newfoundland during 1997. Plant managers were contacted to confirm that posters were received and prominently displayed and that plant workers processing cod were familiar with the details of the tagging program. Local fisheries officers distributed posters widely among fishing communities and posters were sent to fishers on St. Pierre and Michelon. Pre-addressed cod tag return envelopes were sent to processing plants, local fisheries officers, observers, port samplers, and commercial groundfish license holders. All sentinel fishers on the east and northeast coast of insular Newfoundland received posters and tag return envelopes. The reward scheme was also advertised on local radio prior to and during the commercial and recreational fisheries in NAFO subdivision 3Ps. All individuals who returned tags were sent a standard letter describing the date, size, and location where the fish was tagged along with a request to confirm recapture information as well as provide any further recapture details.

Cod were tagged with single yellow (\$10 reward), double yellow (\$20 reward for returning both tags) or single pink tags (\$100 reward). During most tagging experiments the proportion of single, double, and high reward tags applied was approximately 0.45:0.45:0.1; tags were applied in the sequence one pink tag, nine single yellow tags, one pink tag, nine double yellow tags. The tags had the value of the reward printed on them, as well as a serial number and return address.

Data from cod tagged off Little Harbour, Placentia Bay, during 1996 as part of a separate study are also included; these cod were tagged with single red t-bar anchor tags that did not have the value of the reward printed on them. The advertised reward for return of these tags was \$10.

The purpose of the high-reward tags was to estimate the reporting rate of standard \$10 reward tags (see Henny and Burnham 1976; Conroy and Blandin 1984). Initially, we interviewed several fishers to determine a reward amount necessary to ensure that tags would be returned; there was a consensus that a reward of \$100 would achieve this objective. After advertising, contact with a random selection of commercial groundfish license holders confirmed that fishers were knowledgeable of our tag reward scheme. We therefore assumed that those participating in the fishery would return all of the \$100 tags, i.e. the reporting rate for the high-reward tags would be 1.0.

Double tags were applied to provide information on long-term tag loss. Estimates of the rate of tag loss can be obtained from changes over time in the proportion of double tagged cod that are returned with one or two tags (see Seber 1982; Wetherall 1982; Barrowman and Myers 1996).

2.1 Sampling of commercial catch

Information on the length frequency of cod caught in Placentia Bay with different gears during the 1997 commercial fishery was obtained from port sampling and observer records (see Kulka et al. 1998).

2.2 Experiments to estimate short-term tag loss and tagging mortality

2.2.1 Handline-caught cod

During May 1997, four batches of 50 cod were caught in Northwest Arm, Trinity Bay, from a depth of 30 m with hand-lines. Each cod was measured and tagged in the usual manner with single yellow t-bar tags and placed in submersible enclosures (dimensions 2.2 m by 1.2 m by 1.2 m) constructed of 1.0 cm mesh vexar and 1.5 cm aluminum rod. The enclosures were returned to a depth of 30 m close to the tagging site and within 50 m of one another. Surface temperature was recorded during tagging. A thermograph was placed inside two of the four enclosures to monitor water temperature. After 10 days the enclosures were hauled and cod mortality and tag loss evaluated.

2.2.2 Trap-caught cod

On 30th July 1997, a total of 102 cod were obtained from a cod trap off Ferryland from a depth of 26 m. The cod were rather lethargic and many were glutted with capelin which were abundant in the vicinity of the trap. Cod were held at the surface, measured, tagged, placed in approximately equal numbers into two enclosures and returned to the bottom. Temperatures were recorded as described above. After 10 days the enclosures were hauled and cod mortality and tag loss evaluated.

2.3 Estimation of tag reporting rate

The method for estimating reporting rate ($\hat{\lambda}$) and its variance described by Henny and Burnham (1976) and Pollock et al. (1991) was used, except that no tag solicitation was used in this study. The estimate of λ is given by

$$\hat{\lambda} = (R_s/M_s)(R_h/M_h), \tag{1}$$

with variance

$$Var(\hat{\lambda}) = (\hat{\lambda})^2 \left\{(1/R_s) + (\hat{\lambda}/R_s)^2(M_s/M_h)^2 R_h\right\}, \tag{2}$$

where

$$R_s = \text{the number of recoveries of standard (\$10) reward tags,}$$
$$R_h = \text{the number of recoveries of high (\$100) reward tags,}$$
$$M_s = \text{the number of cod released with standard reward single tags,}$$
$$M_h = \text{the number of cod released with high reward tags.}$$

These are equivalent to equations (1) and (2) of Henny and Burnham (1976) except that their SO=0 in our study (therefore their O=HO), and their NO, NR, HO, and R are equivalent to M_s, M_h, R_s, and R_h. As discussed by Pollock et al. (1991), the estimate depends on the assumption that all of the high reward tags are reported. It also depends on the assumption that there is no difference in visibility or rate of tag loss between pink and yellow tags.

2.4 Estimates of exploitation rates on stock sub-components

To illustrate the development of this model, consider an oversimplified example where there is a commercial fishery of short duration with natural mortality occurring only after the fishing season. If M tagged fish are released just before a commercial fishery and there is no tag shedding, tagging mortality, or natural mortality then the expected number of tag returns $E(R)$ from the fishery that year is:

$$E(R) = \lambda \mu M \tag{3}$$

where

λ is the tag reporting rate, and

μ is the exploitation rate or the proportion of fish caught.

Previous tagging studies on cod in Newfoundland have not specifically been designed to provide estimates of how many tags are reported (but see Lear and Rice 1987).

Further modifications of (3) are required to account for various other potential losses of tagged individuals. Some cod may die due to the stress of capture and tagging, and some may die due to natural mortality, particularly if the fishery extends over a long period. Others may lose their tags. If τ is the proportion of fish that die due to the stress of capture and tagging then the expected number of tag returns becomes

$$E(R) = \lambda \mu M(1 - \tau). \tag{4}$$

In this study we caught cod with various gears then tagged and retained them in submersible enclosures to obtain estimates of τ under various conditions.

We assumed that fishing occurred at a fixed time during the year whereas natural mortality and tag loss occurred throughout the year. For each batch of tagged fish, tag loss and natural mortality were assumed to occur over a time period Δt equivalent to the interval between the median date of release and the mean recovery date of tagged individuals within an experiment.

To account for tag loss we used a simple tag shedding model (Beverton and Holt, 1957; Hampton and Kirkwood 1990); if the instantaneous rate of tag loss is constant then the probability that a tag is retained at time t after release is:

$$Q(t) = (1 - \rho)\exp(-\phi)t, \tag{5}$$

where ρ is the proportion of cod that immediately shed there tags and ϕ is the rate of tag loss. In this study we obtained estimates of ρ from the experiments involving retaining batches of tagged cod in submersible enclosures. Our results (see below) indicated that initial tag loss was essentially zero so ρ was dropped from the model. To estimate ϕ, recapture data from the double tagged fish were used. Wetherall and Yong (1981) outline some of the relevant assumptions for analyses of these data. Recaptures of double tagged fish from all experiments were grouped into monthly periods (after release), and the numbers of double tagged fish that had only a single tag on recapture was calculated. The effect of time on the retention of double tags was examined using a generalized linear model with binomial error distribution and a log link function, with the slope of the model being an estimate of ϕ. We also conducted a similar analysis using exact times at liberty though the sample size was much smaller (for many recaptures only the month of recovery was given).

To account for natural mortality, we adopted the approach of Myers et al. (1997) and combined natural mortality and tag loss into a single term. The proportion of fish that survive and retain their tags is therefore $v = \exp(-m-\phi)\Delta t$, where m is the instantaneous rate of natural mortality. Model (4) is modified to account for various sources of loss:

$$E(R) = \lambda\mu M(1 - \tau)v \tag{6}$$

The exploitation rate μ on each batch of tagged fish is therefore:

$$\mu = E(R)/\lambda M(1 - \tau)v. \tag{7}$$

Equation (7) uses the number of standard reward single tags applied (M_s) and reported as recaptured (R_s), together with estimates for the other parameters from high-reward tagging, double tagging, and the retention experiments.

2.5 Model to estimate stock size

We also used the data from the tagging experiments and reported commercial catch to estimate the stock size in Placentia Bay. The 1997 commercial fishery consisted of three main pulses of activity and tag returns and catch associated with each pulse of fishing were grouped. We assume the fishery occurs in P pulses throughout the year, with pulses times $t_1, ..., t_P$ in fractions of years. For the xth tagging experiment, let

- M_x = the number of single tagged fish released in the experiment;
- R_{xt} = the number of these fish returned from fishing pulse t;
- t_{rx} = the time of release;
- t_x = the time of the first fishing pulse following tagging experiment x;
- τ_x = the initial mortality of tagged fish;
- λ_x = the reporting rate;
- ϕ_x = tag loss rate;
- $\Delta t_i = t_i - t_{i-1}$.

There are two parts to the model used to estimate stock size. The first involves expressing the tagging returns in terms of unknown exploitation rates, μ_t's, and the initial releases. The second part of the model involves expressing this exploitation rate in terms of commercial catches, C_t's, and initial stock size, N_o.

We assume a Poisson stochastic model for the number of returns from the first fishery pulse following the experiment x. The rate parameter for R_{xt_x} is

$$\begin{aligned} E(R_{xt_x}) &= \lambda_x \mu_{t_x} M_{t_x} \text{ where} \\ M_{t_x} &= (1-\tau_x) M_x e^{-(m+\phi)(t_x - t_{rx})}. \end{aligned} \tag{8}$$

In this equation $(1-\tau_x)M_x e^{-(m+\phi)(t_x-t_{rx})}$ is the number of tagged fish that survive initial tagging and are available to the fishery, μ_{t_x} is the fraction of these fish that are caught by the fishery, and λ_x is the fraction of the fish caught with tags that are reported. Returns from fishery pulses following t_x will be negatively correlated with R_{xt_x}; that is, if many tags are returned at the first fishing pulse, then fewer are available for capture during subsequent pulses. We assume that $R_{x\,t_{x+k}}$'s are conditionally overdispersed Poisson random variables, with rates

$$\begin{aligned} E(R_{x\,t_{x+k}} | \{R_{xi}\}_{i=t_x}^{t_{x+k-1}}) &= \lambda_x \mu_{t_{x+k}} M_{xt_{x+k}},\ k = 1, ..., \text{ where} \\ M_{xt_i} &= e^{-(m+\phi)\Delta t_i} \left\{ M_{xt_{i-1}} - R_{x\,t_{i-1}} - (1-\lambda_x)\mu_{t_{i-1}} M_{xt_{i-1}} \right\}, \\ &= e^{-(m+\phi)\Delta t_i} \left[\left\{ 1 - (1-\lambda_x)\mu_{t_{i-1}} \right\} M_{xt_{i-1}} - R_{x\,t_{i-1}} \right]. \end{aligned}$$

The conditional variance is $\alpha E(R_{x\,t_{x+k}}|\cdot)$, where α is the Poisson overdispersion parameter. Note that if the reporting rate is one (i.e. $\lambda_x = 1$) then $M_{xt_i} = e^{-(m+\phi)\Delta t_i}\left\{M_{xt_{i-1}} - R_{x\,t_{i-1}}\right\}$.

The other part of the model is

$$\mu_{t_i} = \frac{C_{t_i}}{q_{t_i} N_{t_i}},$$

where q_t is a known proportion of the stock available to the fishery. The N_t's are functions of previous catches and the unknown initial population size. They are defined as

$$\begin{aligned} N_{t_i} &= (N_{t_i-1} - C_{t_i-1})e^{-m\Delta t_i},\ i = 2, \ldots \\ N_{t_1} &= N_o e^{-mt_1}. \end{aligned}$$

The likelihood for N_o given observations of $R_{xt_x}, \ldots, R_{xt_P}$ is

$$L(N_o|R_{xt_x}, \ldots, R_{xt_P}) = \Pr(R_{xt_x}) \Pr(R_{xt_{x+1}}|R_{xt_x}) \cdots \Pr(R_{xt_P}|R_{xt_x}, \ldots, R_{xt_{P-1}}).$$

Each of the probabilities are Poisson in form, so the deviance is

$$\Lambda = \frac{1}{\alpha} \sum_{i=t_x}^{t_P} \left\{\lambda_x \mu_i M_{xi} - r_{xi} \log(\mu_i)\right\},$$

where μ_i and M_{xi} are functions of the unknown initial population abundance, N_o. All other parameters in the functions for μ_i and M_{xi} are assumed to be known, or estimated without error.

3 RESULTS AND DISCUSSION

3.1 Releases of tagged cod

During 1997, 9 tagging experiments were conducted throughout Placentia Bay and adjacent areas in St. Mary's Bay (Division 3L) (Table 1; Fig. 1). A single tagging experiment conducted at Little Harbour, Placentia Bay in June-July 1996 is also included.

Tagging was conducted at four sites near the head of Placentia Bay (one in 1996, three in 1997) prior to the re-opening of the fishery on May 19th, 1997. The remaining taggings were completed at various times after the fishery had reopened. The number of cod tagged and released at each location ranged from 618 to 996. All of the tagged cod were caught in shallow water (range 16-60 m) and each aggregation contained many fish that were in spawning condition.

A wide range of sizes of cod were tagged at each site (Fig. 2). Most were in the range 40-80 cm and tagging encompassed all sizes captured during the commercial fishery (see

Table 1. Summary of details for cod tagging experiments conducted off the south coast of Newfoundland (NAFO Subdiv. 3Ps) and adjacent areas (southern 3L) during 1996 and 1997 (See Figure 1).

Stat. area	Year and expt no.	Dates	Gear	Depth (m)	Number tagged	Mean length (cm)
3Psa	9604	27 Jun.-11 Jul.	cod trap	18	990	55.1
	9701	9-12 Apr.	handline	48-60	996	62.1
	9702	10 Apr.	handline	58-60	966	52.3
	9704	17-18 May	handline	50	817	65.0
	9705	25-28 May	handline	40	709	66.4
	9706	24-26 Jun.	handline	40	963	58.9
	9708	25 Jun.-18 Jul.	trap/handline	18-40	793	53.5
	9715	6-8 Nov.	handline	30-50	778	61.3
3Lq	9707	25-26 Jun.	cod trap	16	701	56.9
	9714	10-14 Oct.	otter trawl	50	618	53.8

below). Mean lengths were variable, but cod tended to be slightly smaller (<60 cm) on the western and southwestern areas of Placentia Bay (Clattice Harbour, Lord's Cove, and Oderin Bank), compared to >60 cm in the eastern and northern areas (Bar Haven, St. Bride's, Iona Islands). The cod tagged at Clattice Harbour were the smallest with a large proportion between 40 and 50 cm.

We also attempted to tag cod offshore in 3Ps and southern 3L during annual research trawl surveys in April and May. However, no significant offshore aggregations were located. We also tagged several hundred cod on the eastern Avalon Peninsula and further north inshore in 3L, but details are not included here due to low tag returns associated with the moratorium (<0.5% have been reported as recaptured). The latter were tagged mainly to look for evidence of movement of cod between 3L and 3Ps in subsequent years and many were released after the 1997 commercial fishery in 3Ps was largely concluded.

3.2 Reported landings from the commercial fishery

During 1997, the commercial cod fishery in Placentia Bay consisted mainly of three short periods of fishing activity, during 19 May - 9 June, 1 - 3 July, and 5 - 6 October; the directed cod fishery was closed to Canadian vessels during the intervening periods. Various combinations of gears were fished during each period, but cod traps were used only during the first two periods. Of the 1560 mT TAC allocated to France, a reported total of 445 mT was landed by the fixed gear fleet from St. Pierre and Michelon which comprised 7

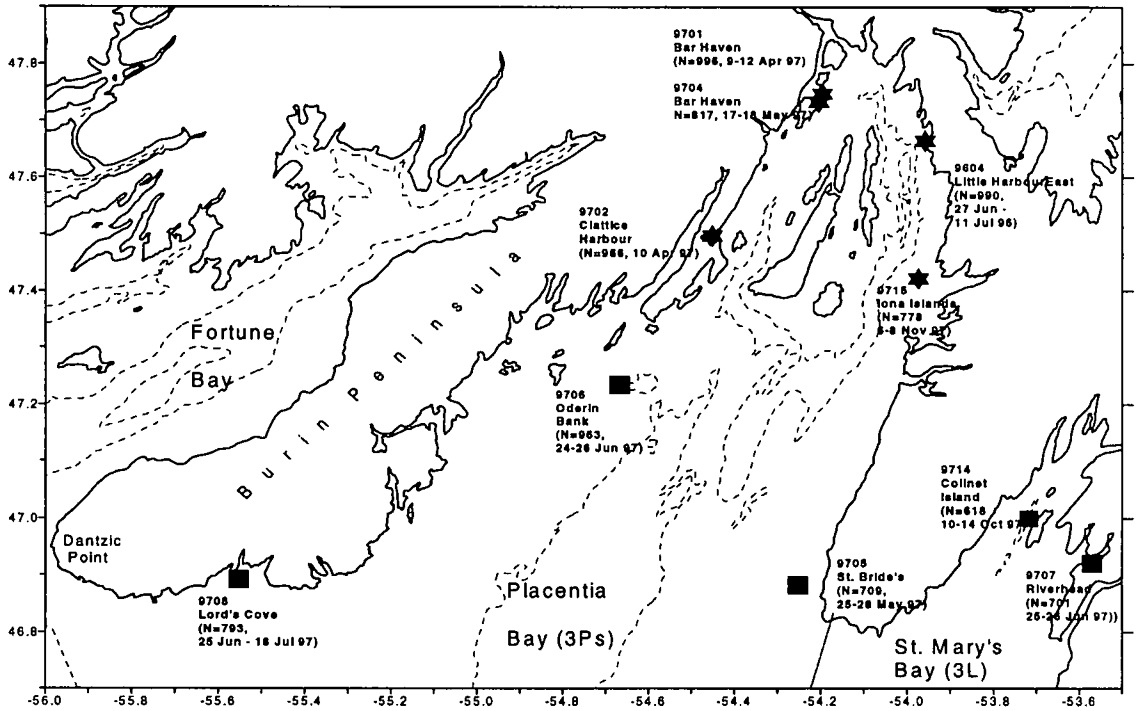

Figure 1: *Experiment number, tagging location, and numbers of cod (N) tagged and released in Placentia Bay and adjacent areas. Stars indicate taggings conducted prior to the reopening of the fishery, squares taggings after the fishery reopened. Dashed line is 200 m depth contour.*

boats of 10-11 m fishing gill nets (284 mT) and 18 boats of <10m fishing hand-lines (171 mT). These boats fished mainly around the Dantzic Point to Lord's Cove area off the tip of the Burin Peninsula (Fig. 1). Specific breakdown of catch by statistical sub-area was not available and we assumed that 75% of the reported fixed gear landings from France came from 3Psc (Placentia Bay). Fishing by French vessels was not restricted to specific time periods and took place throughout April-September and in December, with highest reported monthly landings (74-175 mT) during July-September. The remainder of the French allocation (1038 mT) was landed in St. Pierre and was caught by two chartered Canadian otter trawlers fishing mainly during the fall (Aug.-Dec.) in offshore areas of 3Ps. The sentinel fishery also operated outside the three time periods when the commercial fishery was open to Canadian vessels, but monthly landings were generally less than 50 mT. A recreational fishery in 3Ps employing hook and line and operating on 12-14 and

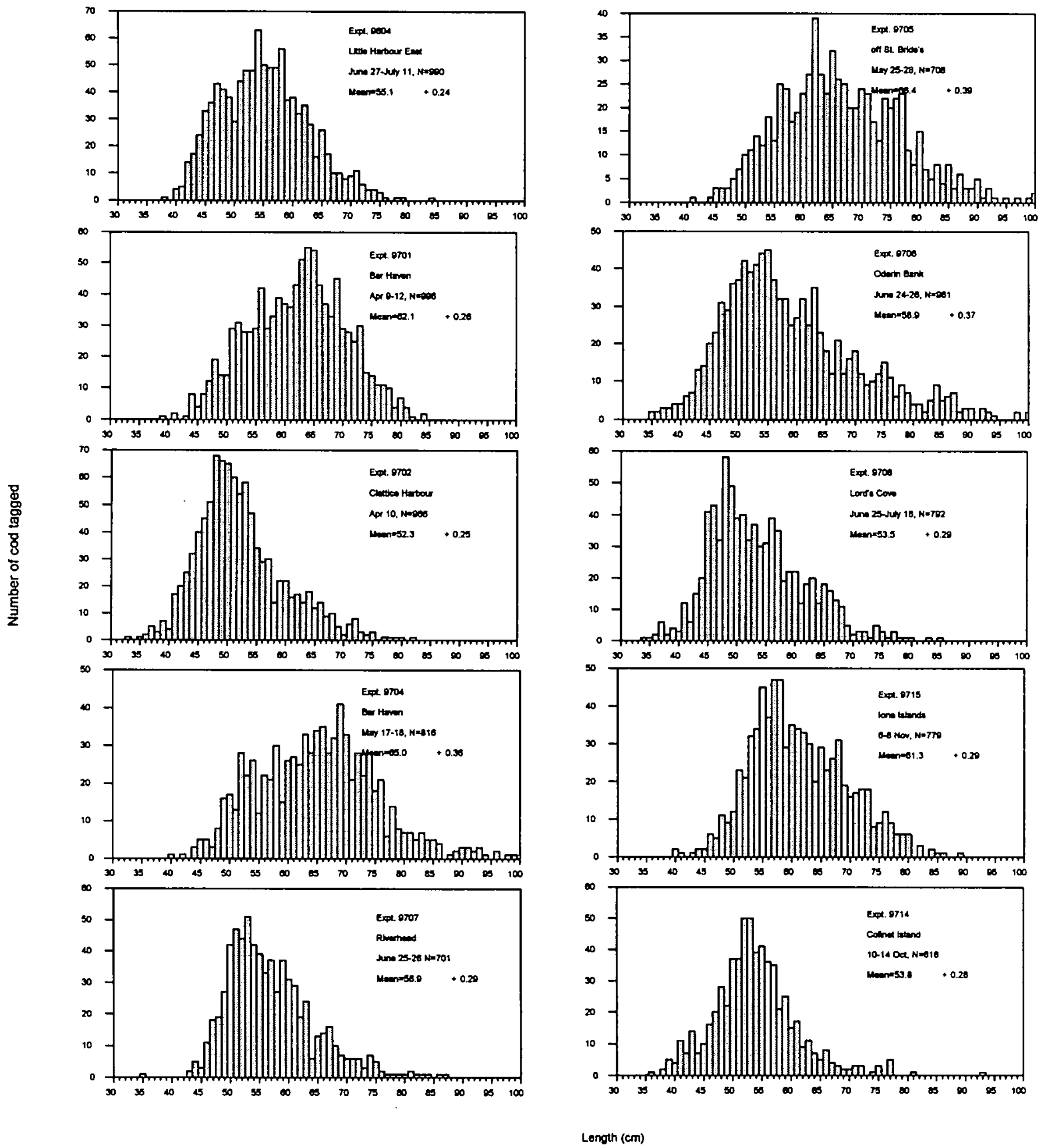

Figure 2: *Size distribution and mean length (±SE) of tagged cod released in 3Ps and adjacent areas in 1996 and 1997.*

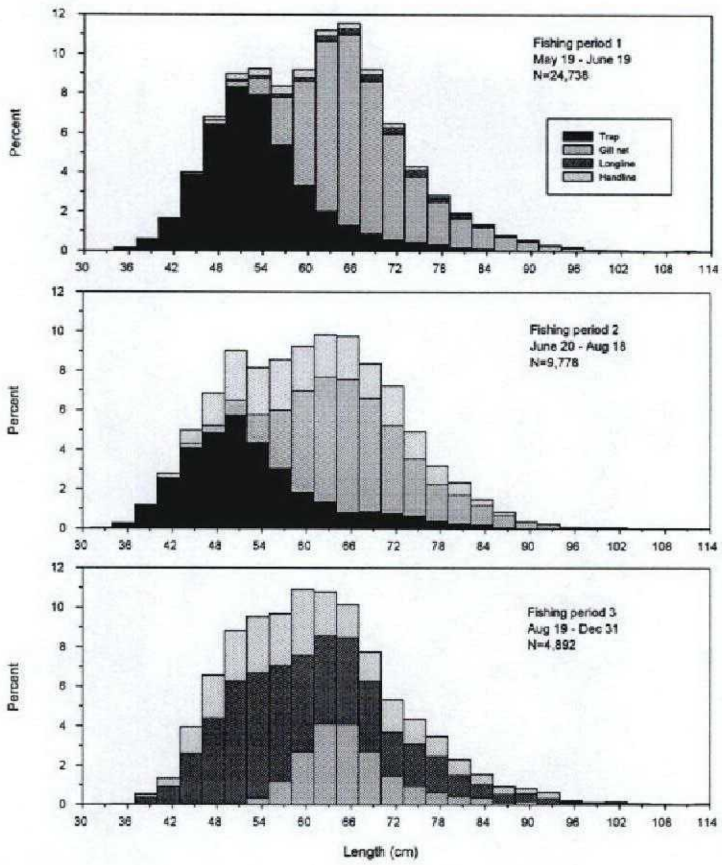

Figure 3: *Length frequency of the catch by gear type for the 1997 commercial cod fishery in Placentia Bay (N = number of cod measured).*

19-21 September caught an estimated 144 mT in Placentia Bay. The Canadian inshore fixed gear sector accounted for most of the reported landings for Placentia Bay, which totaled just over 4,300 mT.

3.3 Sizes of cod recaptured during the 1997 commercial fishery

A wide range of sizes of cod were captured in Placentia Bay during the 1997 commercial fishery (Fig. 3); most cod were between 40 and 80 cm with only a slight change in the size composition of the catch during the three main fishing periods. Two modes in size frequency of the catch were evident during each of the first two fishing periods, at approximately 50 cm and 60-65 cm, respectively. The smaller mode, which is not present in the catch for the third fishing period, appears to have been produced by a large catch of smaller fish by cod traps that were fished only during the first two fishing periods. The larger mode appears to be produced by gill net catches. Hand-lines and line-trawls caught a broader range of sizes of cod.

3.4 Daily pattern of tag returns

The daily pattern of reported catch for Placentia Bay was consistent with the daily pattern of cod tag returns (Fig. 4). Both the timing and the numbers of cod tags returned (from

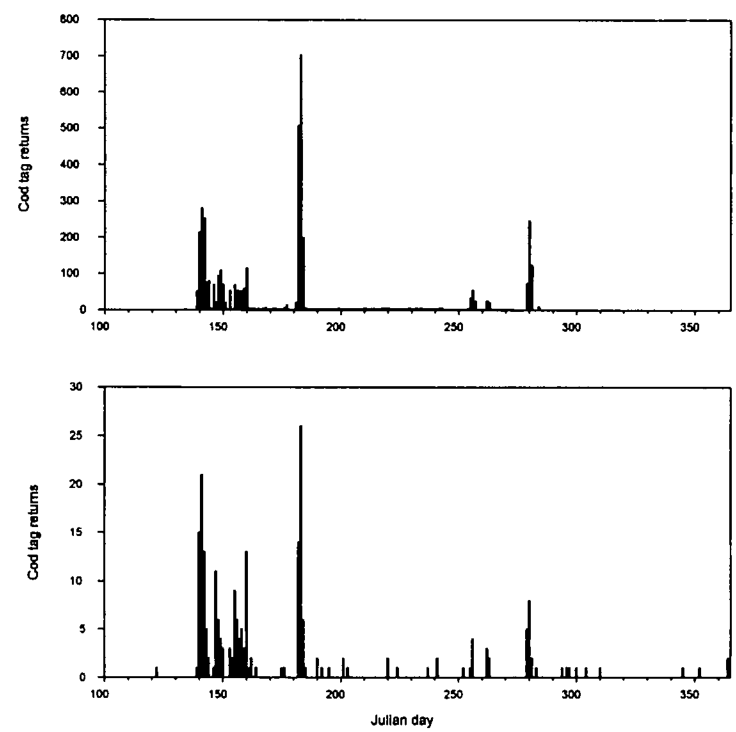

Figure 4: *Reported daily catch of cod and tag returns from fisheries in Placentia Bay during 1997.*

all experiments combined) coincided well with the peaks in reported catch. Small numbers of tags (< 2 day^{-1}) received when the directed cod fishery was closed to Canadian vessels were reportedly from French vessels, Sentinel fishers, or from cod caught as by-catch in fisheries directed at other species (lumpfish, winter flounder, herring, lobster). Overall, these data suggest that the numbers and timing of cod tag returns were consistent with commercial fishing activity.

3.5 Numbers recaptured and reporting rate

Reported recaptures of cod with single standard reward and high reward tags are summarized by experiment in Table 2. For all experiments, the proportions of standard reward

Table 2. Numbers of standard reward and high reward tagged cod released (M_s,M_h) in Placentia Bay and reported as recaptured (R_s, R_h) during 1997 together with proportions (P_s,P_h) and estimates of the reporting rate (λ) and standard error (SE).

Tagging Exp. no.	M_s	R_s	P_s	M_h	R_h	P_h	λ	SE
9604	990	85	0.086	-	-	-	-	-
9701	456	34	0.075	101	17	0.168	0.443	0.130
9702	450	31	0.069	97	7	0.072	0.955	0.400
9704	373	39	0.105	82	10	0.122	0.857	0.303
9705	378	15	0.040	72	3	0.042	0.952	0.602
9706	866	12	0.014	97	4	0.041	0.336	0.195
9708	362	12	0.033	79	4	0.051	0.655	0.378
Pooled	2885	143	0.050	528	45	0.085	0.588	0.099
(excl. 9701)	2429	109	0.045	427	28	0.066	0.684	0.145

tags reported as recaptured (P_s) were low, ranging from 0.014 - 0.105. The proportion returned from a single release of tagged cod in 1996 (expt. 9604, P_s= 0.086) was comparable to that for cod released in the same general area in 1997 (expts. 9701, 9702, 9704, P_s= 0.075 to 0.105). For experiments 9705, 9706, and 9708, which were released during or after the first period of fishing activity, recaptures of standard tags did not exceed 0.04. No recaptures were reported from experiments 9714 and 9715 which were conducted toward the end of 1997 after most of the quota had been caught.

The proportion of high-reward tagged cod reported as recaptured was consistently higher than that of cod with standard reward tags (Table 2), indicating that not all of the standard tags were being reported. Estimates of the reporting rate (λ) for individual experiments were variable, ranging from 0.336 to 0.995. However, for most experiments, except 9701, the number of high-reward tags returned was low (<10) and the individual estimates of λ have high SE's (i.e. >20%). The estimate of λ from all experiments combined (except 9701) indicates that about 68% of the standard reward tags were being reported. We did not investigate spatial heterogeneity in the reporting rate because recaptures were mostly restricted to within Placentia Bay and local fishers moved throughout the bay in search of cod.

Estimates of tag reporting rates are essential for tagging studies that aim to determine exploitation and survival rates. This is the first tagging study of Atlantic cod that used a high reward tag scheme to achieve this objective. Results from the first year suggest that even with a $10 reward a considerable proportion of the tags were not returned by fishers and/or plant workers in spite of an extensive advertising campaign. Discussions with fishers during field trips revealed that many fishers did not think it was worth sending in only one or two standard tags to claim the reward; they expected to get more during the fishing season and said they would wait until they had several, or the fishing season had ended. The pattern of tag returns tended to confirm this comment; a pulse of tags was often received within a week of the closure of the fishery, with some fishers returning several tags obtained throughout the season.

Fishers were often willing to give us tags that they had not sent in when we visited fishing communities during field work. We did not formally include tag solicitation in the design of this study, but it appears that post-season solicitation could be a valuable way to increase the total number of tag returns and hence the amount of information obtained. We also noted that, not surprisingly, the details of recapture were much less well known for tags that fishers had in their possession for several months. An additional means of improving the quality and quantity of recapture information may be to provide the fishers with more feedback on the value of the tagging study and the importance of sending the tags in immediately.

3.6 Recaptures of tagged cod by size

Tagged cod released in Placentia Bay in 1997 prior to the fishery were grouped into 3 cm length groups and the proportions of each length group reported as recaptured during three fishing periods determined (Fig. 5). Tagged cod recaptured within a fishing period were subtracted from the number released to calculate proportions recaptured in subsequent fishing periods. In period 1, the proportion recaptured was generally between 0.05-0.07 across most length classes. We tested the null hypothesis that the proportion of tagged cod recaptured during each period was independent of length using a log-likelihood ratio test (size classes <43 cm and >82 cm were excluded to minimize cell frequencies with counts of 1 or less). For fishing periods 1 and 3, we were unable to reject the null hypothesis (p-value$>$ 0.43 and p-value$>$ 0.14, respectively). For fishing period 2, the proportion recaptured was not independent of cod length (p-value$<$ 0.02). There was no evidence of a distinct trend in the proportion of recaptures across length groups during

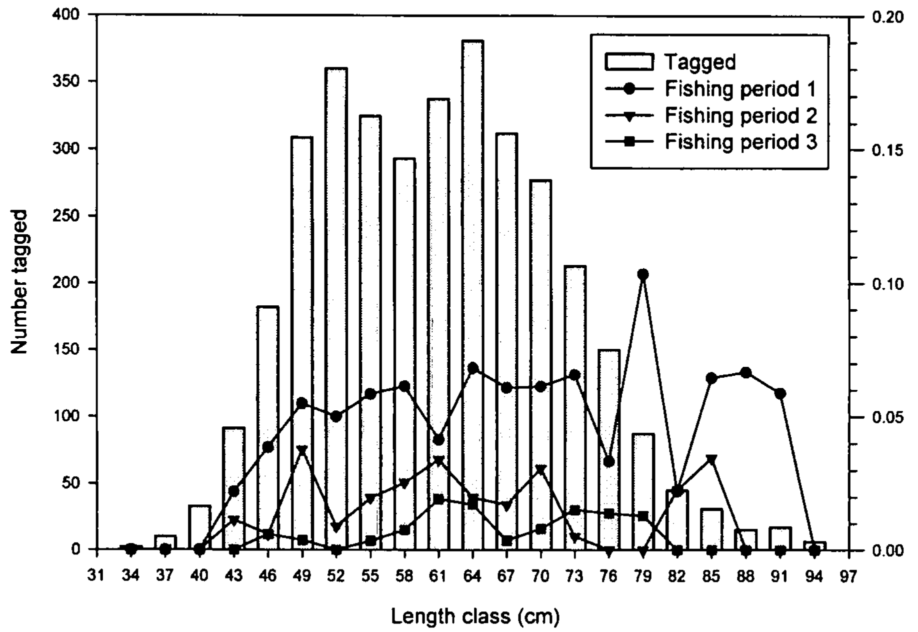

Figure 5: *Proportions of various length classes (3 cm groups) of tagged cod reported as recaptured at three time periods during the 1997 commercial fishery in NAFO subdivision 3Ps. Data from tagging experiments 9701, 9702, 9704, and 9705. Period 1=Jan 1-June 19; period 2=June 20-Aug 18; period 3=Aug 19-Dec 30.*

fishing period 2; the proportions were generally low and fluctuated irregularly between 0 and 0.04. No adjustments were made for growth in these analyses because of the short time interval between release of tagged cod and recapture; similarly proportions recaptured were not adjusted to account for tag loss or natural mortality between fishing periods as we had no length-based information on these parameters. Although various gears with differing selectivities were employed during the three periods of fishing, these analyses indicate that tagging encompassed the broad range of length classes exploited by the commercial fishery, and give no evidence to suggest that the entire fishery selectively exploited specific length or age classes. In future the differential length selectivity by gear type will be explicitly included in analyses.

3.7 Tag loss (ϕ)

The number of double tagged cod reported with only a single tag on recapture was low for recaptures received within a month after tagging but appeared to increase with time

(Table 3). Although there were few double tag returns > 4 months after release, the model

Table 3. Numbers of tags reported at recapture for double tagged cod released in Placentia Bay and adjacent areas during 1997.

No. tags	No. of months since release								
on recapture	0	1	2	3	4	5	6	7	8
1	1	5	6	3	0	2	1	0	0
2	27	58	24	9	4	1	0	0	1

for tag loss fitted the data reasonably well (deviance=7.04, with 6 df) with a significant slope, i.e. instantaneous rate of tag loss of $\phi = -0.073$ month^{-1} ($SE = 0.027$, $p < 0.005$). The estimate for the rate of tag loss is, however, high and we suspect that the reasons for tag loss may be related to handling of fish after capture than actual shedding of tags while fish are at large.

3.8 Tagging mortality (τ) and short-term tag loss

3.8.1 Handline-caught cod

None of the 200 tagged, handline-caught cod retained in submersible enclosures for 10 days lost their tag. Only one cod died and the surviving cod appeared to be vigorous and in good condition. The average size of these cod was 54.3 ±7.8 cm (range 35-77). The temperature at the surface during tagging was 3.0°C and fluctuated between -0.09°C and 0.0°C in the enclosures containing the tagged cod.

3.8.2 Trap-caught cod

A total of 26 of the 102 trap-caught cod (25.5%) were dead when the experiment was concluded after 10 days. One cod had lost the tag. The surviving cod appeared vigorous and in good condition. The average size of these cod was 60.9 ±9.76 (range 41-82). The water temperature at the surface during tagging was $6.0°C$ and fluctuated irregularly between $-1.0°C$ and $7.2°C$ in the enclosures containing the tagged cod.

The combined results from the retention experiments revealed that only 1 of 276 cod that were still alive had lost a tag within 10 days; therefore, we assumed that initial tag loss was close to nil and we did not include a parameter for this in the model. The average size of cod used in the experiments was similar to that of tagged cod that were released (Fig. 2). The proportion of cod that died differed considerably between experiments and we suspect that the range of mortalities observed represent approximate maxima and minima likely to be experienced for inshore shallow water tagging of handline and trap-caught cod, respectively. For the model to estimate exploitation rate on stock components we used an intermediate value of $\tau = 0.05$ (i.e. 5% mortality). Most of the tag release experiments were conducted with handline-caught fish in early spring when waters were cold (<3.0°C), i.e. under conditions similar to those of the retention experiment with handline-caught cod.

3.9 Estimates of exploitation rate (μ) on stock sub-components

We used recapture data and results from the experiments to provide inputs for equation (7) and produce estimates of the exploitation rate (μ) on cod tagged in each experiment. A summary of inputs together with estimates of μ is given in Table 4. Reporting rates

Table 4. Estimated exploitation rates on sub-components of the 3Ps cod stock tagged in Placentia Bay prior to and during the 1997 commercial fishery. The tag loss rate exponent (ϕ) was estimated at 0.073/month, the instantaneous natural mortality rate (m) was assumed 0.2/yr, and short-term tagging mortality (τ) was estimated at 0.05 for all tagging experiments (see text for details).

Tagging experiment number	Days until recaptured t	Number tagged M_s	Number reported as recaptured R_s	Reporting rate λ	Exploitation rate μ
9701	62.3	456	34	0.443	0.213
9702	58.3	450	31	0.684	0.126
9704	18.1	373	39	0.684	0.170
9705	81.0	378	15	0.684	0.078
9706	93.0	866	12	0.684	0.028
9708	28.1	362	12	0.684	0.055

(λ) for most tagging experiments had high variance and we used the pooled estimate of λ that excluded data from expt 9701 to estimate μ for each batch of tagged cod. For expt. 9701 we used the experiment-specific estimate. Estimates of exploitation rate averaged 0.17 and ranged from 0.126 to 0.213 for aggregations of spawning cod tagged at the head of Placentia Bay prior to the fishery opening (i.e. expts 9701 to 9704). For a large spawning aggregation tagged near St. Bride's 5-9 days after the fishery began the estimate was 0.078. The remaining estimates, which are lower (0.028 to 0.055), are also for cod tagged at various intervals after the fishery had started; the total exploitation rates on these aggregations is higher due to removals by the fishery prior to tagging. These latter experiments were conducted when less than half the quota had been caught and it is unlikely that the total exploitation rates for these stock components would be more than double those reported here.

3.10 Model to estimate overall exploitation rate and stock size

We used a combination of data from the tag recaptures, experiments, and commercial catch to obtain inputs for the model to estimate stock size. We grouped the fishing season into three time periods (julian days 1-170, 171-230, and 230-365) that corresponded to the three main pulses of fishing activity (see Fig 4.). A weighted midpoint for these three time periods was computed as the catch weighted average of julian days within each period. Midpoint dates for the three periods were (in julian days) 147.2, 185.9, and 277. All reported catches within these time periods were combined giving 1842, 1665, and 840 mT respectively (Table 5). The number of returns of single standard reward

Table 5. Summary of inputs from the 1997 commercial catch for the model to estimate stock size. The commercial fishery in Placentia Bay occurred in three pulses, with times of pulses $t_1, ...t_3$ in fractions of years

pulse i	date t_i	Reported weight (mT)	catch (000's) C	Δt
1	0.40329	1842.2	1023.55	0.40329
2	0.50932	1664.7	924.86	0.10603
3	0.75990	839.7	466.50	0.24959

tags from each experiment within these time periods was also computed (Table 6). Dates of release (expressed as fractions of a year) for each tagging experiment were also used. When tagging extended over several days we used the median date of release. In the model we assumed that all fishing and tag returns occurred only at the midpoint of each period of fishing activity (expressed as fractions of a year) whereas natural mortality (assumed 0.2 yr^{-1}), and tag loss occurred only between the median date of release and the midpoint dates of each pulse of fishing. Values for reporting rate, tagging mortality, and tag loss were the same as those used in the model to estimate exploitation rate of stock components (Table 4).

Table 6. Summary of inputs from the tagging data for the model to estimate exploitation rate associated with each period of fishing and stock size in Placentia Bay.

Expt. no. x	Median release date t_r	Number of tagged cod released M	Fishing pulse P	Median date t	Number reported as recaptured R
9701	0.27945	456	1	0.40329	21
			2	0.50932	5
			3	0.75890	4
9702	0.27397	450	1	0.40329	21
			2	0.50932	8
			3	0.75890	0
9704	0.37534	373	1	0.40329	27
			2	0.50932	5
			3	0.75890	2
9705	0.39726	378	1	0.40329	3
			2	0.50932	5
			3	0.75890	5
9706	0.48493	866	2	0.50932	3
			3	0.75890	7

Outputs from the model to estimate stock size and exploitation rates associated with each period of fishing are summarized in Tables 7a,b. The profile deviance CDF for N_o (initial stock size in Placentia Bay) is presented in Figure 6. The estimate of N_o is 26 million fish or about 52,000 mT based on an average (commercial) weight of approximately 2.0 kg. Estimates of exploitation rate associated with each period of fishing ranged from 0.0425 for the first period to 0.023 for the third. For three of the five tagging experiments (expts. 9701, 9702 and 9704) the observed numbers of tag returns for the first period of fishing were considerably higher than those from the second period (Table 7b), even though the reported catch for these two fishing periods was similar. This result is also reflected in the model fits to the data for these experiments, with the expected number of tag returns showing high positive deviance residuals for the first fishing period. The overall model fit also shows evidence of overdispersion ($\alpha = 7.18$).

One interpretation of these results is that tagged fish were not thoroughly mixed with other members of the local population during the first period of fishing. To investigate this possibility further, we examined plots of the spatial distribution of tag returns associ-

Table 7a. Estimated Placentia Bay population size and exploitation rates during the three fishing pulses t.

t	$C_t \times 10^{-6}$	$N_t \times 10^{-6}$	μ_t
147.2	1023.5	24089.8	0.0425
185.9	924.9	22582.3	0.0410
277.0	466.5	20602.9	0.0226

ated with the first period of fishing; these (see Lawson et al. 1998) indicated that tagged cod were well distributed away from the tagging site, particularly along the eastern side of Placentia Bay. We examined the number of tag returns received per experiment from individual fishing enterprises; these rarely exceeded two tags suggesting tagged cod were dispersed. We also examined the number of tag returns from a tagging experiment conducted in Placentia Bay in 1996 (expt 9604); for the three fishing periods the numbers of reported recaptures were 46, 13, and 22, respectively, plus four tags with no date of recapture. Clearly, this experiment also indicates a disproportionately high number of tag returns associated with the first period of fishing, yet these fish were tagged almost a year before the fishery began and were well dispersed from the tagging site in the spring of 1997 (see Lawson et al. 1998). An alternative explanation for these findings is that the first fishing period exploited mainly inshore (local) spawning groups, and that during the second and third periods there was immigration into the study area of other stock components that were not tagged. Historical 3Ps cod tagging experiments (summarized by Taggart et al. 1995 and Brattey 1996) support this suggestion and show, for example, that a proportion of cod tagged on Burgeo Bank during winter migrate inshore during late spring and summer and contribute to inshore fisheries including those in Placentia Bay. Tag returns from the present study also show some evidence of migration of cod between Fortune Bay and the western side of Placentia Bay (Lawson, Rose and Brattey 1998).

The lower returns of tagged cod during the second and third fishing periods may also be attributed, in part, to movement of tagged fish out of Placentia Bay. The geographic distribution of tag recaptures clearly indicates that many cod tagged at the head of Placentia Bay moved south then eastward during spring and summer. There were many recaptures off Cape St. Mary's next to the boundary with NAFO Div. 3L (Lawson et al. 1998). The directed cod fishery in 3L remains under moratorium and fishing activity in 3L during 1997 was restricted to sentinel fishers, bycatch, and illegal fishing. In spite of the low fishing effort and reported landings of only 343 tons (Lilly et al., 1998), there were tag returns from several inshore locations around the Avalon Peninsula and as far north as Trinity Bay. The plots given in Lawson et al. (1998) slightly underestimate

Table 7b. Model predicted tag returns, and residuals.

Experiment x	Release time, t_{rx}	R_{xt}	Return time, t_i	$E(R_{xt})$	Deviance	Residuals Deviance	Residuals Chi-square
		21	0.4033	6.89	18.60	4.31	5.38
456	0.2795	5	0.5093	5.42	0.03	-0.18	-0.18
		4	0.7589	2.17	1.23	1.11	1.24
		21	0.4033	10.98	7.20	2.68	3.02
450	0.2740	8	0.5093	8.74	0.06	-0.25	-0.25
		0	0.7589	3.51	7.02	-2.65	-1.87
		27	0.4033	10.20	18.97	4.36	5.26
373	0.3753	5	0.5093	7.93	1.25	-1.12	-1.04
		2	0.7589	3.21	0.53	-0.73	-0.68
		3	0.4033	10.59	7.62	-2.76	-2.33
378	0.3973	5	0.5093	8.87	2.01	-1.42	-1.30
		5	0.7589	3.60	0.49	0.70	0.74
		3	0.5093	22.92	27.63	-5.26	-4.16
866	0.4849	7	0.7589	9.42	0.68	-0.83	-0.79

the numbers of cod recaptured in 3L as only those with precise recapture positions are shown; some tags are reported with only the name of the bay or DFO statistical fishing area (i.e. 3Lq, 3Lj, etc.). Of the 287 recaptures reported from experiments 9701, 9702, 9704, and 9705 with information on at least the general recapture area, a total of 4.9% were recovered from 3L.

Our analyses suggest that inshore cod that aggregate to spawn at the head of Placentia Bay during spring are particularly prone to heavy exploitation when the inshore cod fishery is opened early in spring. Although overall exploitation of these stock components during 1997 does not appear to be excessive, fishing removed about 17% of these cod, mostly in the first fishing period. This is also consistent with the positive residuals we observed for the first fishing pulse (see Table 7b). Many licence holders did not fish for cod in 1997 because of the small quota; consequently, exploitation rates on these stock components could be significantly higher if a larger quota was combined with early opening of the fishery. Scheduling of a larger portion of the inshore quota to later, possibly July, would allow these fish to complete spawning, disperse, and mix with other stock components that enter the bay later during spring and summer. The catch could then be spread among more stock components thereby reducing the fishing pressure on any one component.

The results of the tagging study also suggest that any reopening of the commercial

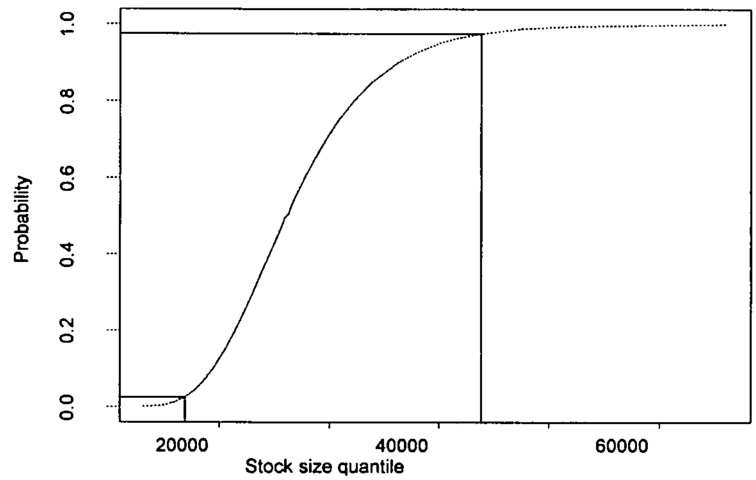

Figure 6: *Profile deviance CDF for initial stock size (numbers in 1000's) in Placentia Bay. The solid lines connect the endpoints of the* 95% *confidence interval.*

cod fishery in the inshore of southern 3L during summer would result in additional fishing mortality on the inshore 3Ps stock component that spawns at the head of Placentia Bay. Current results are based on a single year of tag returns and recaptures from subsequent years should confirm whether this migration is an annual occurrence.

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References

[1] Barrowman, N. J. , and R. A. Myers. 1996. Estimating tag shedding rates for experiments with multiple tag types. Biometrics 52: 1410-1416.

[2] Beverton, R. H. J., and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest. Ser. II, Mar. Fish. G. B. Minist. Agric. Fish. Food 19, 533 p.

[3] Brattey, J. 1996. Overview of Atlantic cod (*Gadus morhua*) stock structure in NAFO Subdivision 3Ps inferred from tagging studies. DFO Atl. Fish. Res. Doc. 96/93.

[4] Brownie, C., K. P. Burnham, and D. S. Robson. 1985. Statistical inference from band recovery data-handbook 1985. U.S. Fish Wildl. Serv. Resour. Publ. 156: 305pp.

[5] Campana, S. E., G. Chouinard, M. Hanson, A. Fréchet, and J. Brattey. 1998. Stock composition of cod aggregations near the mouth of the Gulf of St. Lawrence in January 1996 based on an analysis of otolith elemental fingerprints. CSAS. Res. Doc. 98/55

[6] Conroy, M. J., and W. W. Blandin. 1984. Geographic and temporal differences in band reporting rate for American black ducks. J. Wildl. Managmt. 48: 23-36.

[7] D'Amours, D., K. T. Frank, and G. Bugden. 1994. Report of the working group on oceanographic effects on stock migration and mixing reviewed by the Fisheries Oceanography Committee (FOC). DFO Atl. Fish. Res. Doc. 94/54.

[8] Hampton, J., and G. P. Kirkwood. 1990. Tag shedding by southern bluefin tuna *Thunnus maccoyii.* Fish. Bull. 88: 313-321.

[9] Henny, C. J., and K. P. Burnham. 1976. A reward band study of mallards to estimate band reporting rates. J. Wildl. Managmt. 40: 1-14.

[10] Kulka, D. W., T. Inkpen, and M. O'Connor. 1998. A description of the 1997 Atlantic cod fishery in NAFO Division 3Ps from port sampling and fishery observer records with a comparison to the sentinel and food fisheries. CSAS. Res. Doc. 98/61.

[11] Lawson, G. L., G. A. Rose, and J. Brattey. 1998. Movement patterns of inshore cod in Subdivision 3Ps (southern Newfoundland) based on mark-recapture studies during 1996-97. CSAS. Res. Doc. 98/24.

[12] Lear, W. H. 1984. Results of tagging of Atlantic cod on St. Pierre Bank during February, 1980. NAFO SCR Doc. 25 (Ser. No. N806): 1-4.

[13] Lear, W. H. 1988. Distribution of recapture of cod tagged on Burgeo Bank during March 1986. NAFO SCR Doc. 71 (Ser. No. N1514): 1-8.

[14] Lear, W. H., and J. C. Rice. 1987. Proportions of Atlantic cod (*Gadus morhua*) of the 2J3KL stock components taken by the inshore fishery as estimated by offshore tagging. CAFSAC Res. Doc. 87/3: 1-26.

[15] Lilly, G. R., Shelton, P.A., Brattey, J., Cadigan, N.G., Murphy, E. F., Stansbury, D. E., Davis, M.B., and Morgan, M.J. (1998) An assessment of the cod stock in NAFO Divisions 2J+3KL. CSAS. Res. Doc. 98/15.

[16] Moguedet, P. 1994. Cod (*Gadus morhua*) migrations in the Gulf of St. Lawrence and areas south of Newfoundland. NAFO Sci. Coun. Studies 22: 71-84.

[17] Myers, R. A., N. J. Barrowman, J. M. Hoenig, and Z. Qu. 1996. The collapse of cod in eastern Canada: the evidence from tagging data. ICES J. Mar. Sci 53: 629-640.

[18] Myers, R. A., N. J. Barrowman, and J. A. Hutchings. 1997. Inshore exploitation of Newfoundland Atlantic cod (*Gadus morhua*) since 1948 as estimated from mark recapture data. Can. J. Fish. Aquat. Sci. 54(Suppl): 224-235.

[19] Myers, R. A. and J. M. Hoenig. 1997. Direct estimates of gear selectivity from multiple tagging experiments. Can. J. Fish. Aquat. Sci. 54:1-9.

[20] Pollock, K. H., J. M. Hoenig, and C. M. Jones. 1991. Estimation of fishing and natural mortality when a tagging study is combined with port sampling. Am. Fish. Soc. Symp. 12: 423-434.

[21] Rollet, C., A. Frechet, A. Battaglia, J.-C. Brethes. 1994. Modification de distribution du stock de morue du nord du golfe du Saint-Laurent (3Pn-4RS) et hiver. DFO Atl. Fish. Res. Doc. 94/82.

[22] Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. 2nd ed. MacMillan Publishing Co., Inc., New York, NY. 654pp.

[23] Shelton, P., D. E. Stansbury, E. F. Murphy, G. R. Lilly, and J. Brattey. 1996. Assessment of the cod stock in NAFO Subdivision 3Ps. DFO Atl. Fish. Res. Doc. 96/91.

[24] Taggart, C. T. P. Penney, N. J. Barrowman, and C. George. 1995. The 1954-1993 Newfoundland cod-tagging database: statistical summaries and spatial-temporal distributions. Can. Tech. Rep. Fish. Aquat. Sci. 2042: 441p.

[25] Templeman, W. 1974. Migrations and intermingling of Atlantic cod (*Gadus morhua*) stocks of the Newfoundland area. J. Fish. Res. Board Can. 31: 1073-1092.

[26] Templeman, W. 1979. Migration and intermingling of stocks of Atlantic cod, *Gadus morhua*, of the Newfoundland and adjacent areas from tagging in 1962-66. ICNAF Res. Bull. 14: 5-50.

[27] Wetherall, J. A. and M. Y. Y. Yong. 1981. Planning double-tagging experiments. NOAA Tech. Mem. NMFS 13: 44p.

[28] Wetherall, J. A. 1982. Analysis of double-tagging experiments. Fish. Bull. 80: 687-701.