Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S
Canadian Science Advisory Secretariat

S C C S
Secrétariat canadien de consultation scientifique

Research Document 2006/002

Document de recherche 2006/002

Not to be cited without
permission of the authors *

Ne pas citer sans
autorisation des auteurs *

Estimated discards of winter skate (*Leucoraja ocellata*) in the southern Gulf of St. Lawrence, 1971-2004

Estimation des prises rejetées de la raie tachetée (*Leucoraja ocellata*) dans le sud du golfe du Saint-Laurent, 1971-2004

H.P. Benoît

Fisheries and Oceans Canada, Gulf Fisheries Centre,
P.O. Box 5030, Moncton, NB, E1C 9B6

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Winter skate (*Leucoraja ocellata*) in the southern Gulf of St. Lawrence form a distinct population (designatable unit) that is currently considered to be endangered by the Committee on the Status of Endangered Wildlife in Canada. The causes of the decline in population status have not been established, but bycatch in fisheries targeting other species is believed to be an important contributing factor. The present document aims to contribute to better understanding the causes of decline and assessing the recovery potential of southern Gulf winter skate by providing estimates of bycatch levels for this population in groundfish and shrimp fisheries, over the period 1971-2004. Data from at-sea observers were used to this end. However, problems with the taxonomic identification of skates by those observers necessitated the use of empirical models to predict species identity when estimating discards. The statistical error associated these predictions, as well as with two other steps involved in inferring total discards from the subset of fishing trips that are covered by observers, was propagated to the overall estimates using non-parametric bootstrapping methods. The highest estimated median discard levels occurred during the early 1970s, at about two-thousand tonnes annually. Discard estimates decreased to generally under one-hundred tonnes by the early 1990s and under fifty tonnes in the 2000s. The results of three studies (one recent and two previously published) suggest that the mortality rate of these discarded skate is likely at least 50%.

RÉSUMÉ

La raie tachetée (*Leucoraja ocellatta*) du sud du Golfe du St. Laurent forme une population distincte qui est présentement considérée comme menacée par le Comité sur la situation des espèces en péril au Canada. Les facteurs contribuant au déclin de cette population ne sont pas connus présentement. Cependant les prises accessoires dans les pêcheries commerciales visant d'autres espèces pourraient être un facteur important. Le document présent a pour but de contribuer à évaluer cet impacte en fournissant des estimations de niveaux de prises accessoires de raie tachetée dans les pêcheries au poisson de fond et à la crevette, pour la période de 1971-2004. Ces calculs furent basés sur les donnés récoltées par des observateurs en mer. Cependant, dû à des problèmes avec l'identification des diverses espèces de raies par les observateurs, des corrections basées sur des modèles empiriques ont été employées lors des calculs. Ces corrections ainsi que certains calculs intermédiaires apportent une erreur statistique lors des estimations de prises accessoires. Afin de mieux comptabiliser cette erreur, des techniques de propagation d'erreur basées sur des méthodes de réechantillonnage par bootstrap furent employées. Les niveaux moyens de prise accessoire les plus élévées, d'environ deux mille tonnes métriques par année, furent calculés pour les années 1970. Ces niveaux ont baissé à moins de cent tonnes annuellement par le début des années 1990 et à moins de cinquante tonnes dans les années 2000. Deux études publiées et une étude récente suggèrent un taux de mortalité d'au moins 50% de ces prises accessoires qui sont le souvent rejetées en mer.

INTRODUCTION

Winter skate (*Leucoraja ocellata*) in the southern Gulf of St. Lawrence form a distinct population (designatable unit) that is currently considered by the Committee on the Status of Endangered Wildlife in Canada to be at a high risk of extirpation (i.e., designated as *endangered*) (COSEWIC 2005). The causes of the decline in population status have not been established, but bycatch in fisheries targeting other species is believed to be an important contributing factor (COSEWIC 2005). The present working paper aims to contribute to a better understanding of the causes of decline and assessing the recovery potential of southern Gulf winter skate by providing estimates of bycatch levels for this population in groundfish and shrimp fisheries, over the period 1971-2004. It was also deemed important to obtain measures of the full uncertainty around these estimates which involve extrapolating from fishery-dependent surveys to entire fishing fleets. Error propagation methods (e.g., Blukacz et al. 2005; Efron and Tibshirani 1993) were therefore used to account for the variability associated with the various data sources and the steps involved in calculating the estimates (e.g., Rochet and Trenkel 2005).

Background

Skates in the southern Gulf are generally discarded at sea and are therefore rarely recorded in commercial fishery landing statistics (see *Results*; Swain et al. 2005). Even when they are landed, they are not separated by species. Data on bycatch amounts and species composition collected by at-sea observers in groundfish, herring purse-seine and shrimp fisheries are therefore the only large-scale source of information on the rate at which winter skate, and other discarded species, are captured during certain commercial fishing operations. Information on fish bycatch in scallop dredge and crustacean trap fisheries is currently not collected by observers in the Gulf of St. Lawrence.

The Atlantic Canadian international observer program was introduced to the Gulf of St. Lawrence domestic fleet in 1990. Harvesters participating in fisheries covered by the program must allow observers onboard their vessels as a condition of their fishing license. Observers are deployed by fishing regulatory regime (hereafter termed *fishery*), which is determined by the species sought, the type of gear used, the fishing area and in some cases vessel length. Target observer coverage levels in finfish and shrimp fisheries have generally been between 5-10% of fishing trips, depending on the year and fishery (*H.P. Benoît and J. Allard, in prep.*). However, actual observer coverage was very low during the first year of the program, increasing considerably thereafter. Consequently only data collected from 1991 onwards are included in estimating winter skate catches.

METHODS

The majority of studies aimed at estimating discards do so as a function of the amount of fish landed (i.e. kg discarded species per kg of landed species) or as a function of fishing effort measured in time spent fishing (Rochet and Trenkel, 2005). These model-based approaches assume that discards are proportional to catch and hence landings of commercially important species in the case of the former, and proportional to fishing time in the latter. In their review, Rochet and Trenkel (2005) found little support for these assumptions as the relationships are often very weak or non-linear. They therefore recommend that inference from observed fishing sets to the entire fishery be done using design-based methods founded on sampling theory, i.e., raising by the sampling units (fishing sets, or at least fishing trips). However, such an approach is possible in the Gulf of St. Lawrence only for a limited number of years owing to a lack of information on the total number of trips (let alone fishing sets) undertaken by fishers. Reliable trip-by-trip landings and fishing activity information is generally only available as of the late 1980s for mobile gear groundfish vessels longer than 45 feet and as of 1998 for most fixed gear vessels. As a result, inference on catches of winter skate across all fisheries prior 1998 must necessarily be done as a function of landings of commercially important species rather than by trips. However, the observer data were examined for strong violations of the assumption of proportionality between winter skate and commercial fish species catches. Furthermore, winter skate catches estimated based on trips were compared to those based on landings for mobile gear fisheries over the period in which the former estimates are possible (see *Results*).

In their review, Rochet and Trenkel (2005) also found that the type of fishery (i.e., targeted species, gear, mesh size, etc.) can have a significant impact on discard rates. As such, it would have been preferable for winter skate bycatch rates to be calculated by fishery, as a function of the retained catch of the targeted species. For each targeted species these bycatch rates could then have been raised by their total directed landings and summed across species to arrive at an annual estimate of total winter skate catch. Although it is possible to calculate the fishery-specific bycatch rates from the observer data, the landings data prior to the 1990s generally do not distinguish between directed and incidentally captured landings of commercially important species. Raising the “directed” bycatch rates by the total landings prior to the 1990s would result in over-estimates of winter skate discard levels. Consequently, bycatch rates in each fishery were calculated for each of eleven commercially important species which were captured along with winter skate at least some of the time. The calculation of final annual bycatch rates for each of the eleven species includes stratification across fisheries, by weighting by the landings of that species in each fishery. (Stratifying by fishery makes sense from an experimental design stand-point, as observers are deployed by fishery). Thirteen fisheries were included in the analysis: cod (*Gadus morhua*) fixed and mobile gear, spiny dogfish (*Squalus acanthias*), Atlantic halibut (*Hippoglossus hippoglossus*), Greenland halibut (*Reinhardtius hippoglossoides*), redfish

(*Sebastes* sp.), American plaice (*Hippoglossoides platessoides*), winter flounder (*Pseudopleuronectes americanus*) fixed and mobile gear, white hake (*Urophycis tenuis*), witch flounder (*Glyptocephalus cynoglossus*), yellowtail flounder (*Limanda ferruginea*) and shrimp (*Pandalus* sp.). The estimated annual bycatch rates are also stratified by province and by fleet (i.e., competitive vs. individual transferable quota - ITQ) as the deployment of observers has been found to be non-random among fishing districts (*province* is used as a proxy here for district because of a number of missing entries) and between fleets (*H.P. Benoît and J. Allard, in prep.*).

Sources of bias and variability in the data used to estimate bycatch rates

If one assumes that observers are deployed randomly or systematically, and that captains do not modify their fishing behaviour in the presence of observers, then winter skate catches by the entire fleet can be estimated from the catches by observed fishing vessels. However, there is question whether these assumptions hold for the Gulf of St. Lawrence observer data (*H.P. Benoît and J. Allard, in prep.*), potentially resulting in an unquantified bias if those data are used to estimate total bycatch. Nonetheless, in the absence of other data on discard rates, winter skate catches are estimated in light of these issues, while taking into account the other sources of uncertainty discussed in this section.

Data on non-commercially important species collected by at-sea observers can suffer from varying degrees of imprecision and inaccuracy in taxonomic identification owing to the lack of formal training of many at-sea observers and to time constraints when sampling catches. In many instances, taxa, including skates, are identified only at coarser taxonomic levels such as Order or Family. Imprecise identification is a problem when estimating winter skate bycatch rates in the Gulf of St. Lawrence where about thirty percent of records of skate capture during commercial fishing activities are not attributed to species (Table 1). Additionally, there are a number of records in which the taxonomic identification is not consistent with the known geographic or bathymetric distribution or perceived relative abundance of the species in question (Table 1; see also *Results*). For example, observers in the Gulf of St. Lawrence have identified spinytail skate (*Bathyraja spinicauda*) much more often than would be expected based on research surveys and ichthyological collections (Benoît et al., 2003b; Scott and Scott 1988), suggesting a probable misidentification of thorny skate (*Amblyraja radiata*).

Fortunately, problems with taxonomic identification can potentially be addressed using empirical models based on habitat or geography. Because winter skate in the southern Gulf of St. Lawrence generally have a spatial distribution that is distinct from other skates in the area in most seasons (Darbyson and Benoît, 2003; Clay, 1991) such an approach is possible. Here a series of logistic-regression models derived from research survey data and based on depth and season are used to predict the proportion of skates captured that are winter skate. Then, making the reasonable assumption that observers can correctly distinguish skates from other finfish (*H. Benoît, personal observation*), the total catch of skates in a fishing set are multiplied by the predicted proportion to obtain a predicted amount of winter skate. However, such predictions are associated with uncertainty that needs to ultimately be incorporated in the final bycatch estimates. The manner in which this was done is described in the next section.

Inferring winter skate catches from landed commercial catch in years when no at-sea observations of bycatch rate (kg winter skate per kg of landed species) were made (i.e., prior to the 1990s) requires important assumptions about species mixes in commercial fishing catches. First, it assumes that the bycatch rates do not vary inter-annually, regardless of the relative abundance of the species. Secondly, it assumes either that the manner in which the commercially-important fish species are captured does not affect the bycatch rates of winter skate or that it has not changed over time. As explained below, both assumptions are likely violated, but it may be possible to correct for the first one.

Clearly, bycatch rates must reflect the relative abundance of the incidentally captured and the sought species in some manner (e.g., when one becomes locally very rare or absent), although the relationship may not be linear. Given the large changes in the abundance of southern Gulf winter skate and of many commercially important fish species in the southern Gulf (Benoît et al., 2003a), it is unlikely that bycatch rates have not varied inter-annually. Data on the relative abundance of species from research surveys can be used to correct the bycatch rates when making inference about past catches if one is willing to assume that the two are proportional. For lack of a more appropriate way to proceed this approach was adopted here. However, given that survey abundance indices are not estimated without error, the associated uncertainty was also incorporated in the final winter skate catch estimates.

Violations of the second assumption regarding bycatch rates are much more difficult to deal with because the assumption implies, among other things, that any modifications to fishing gear (e.g., changes in mesh size) occurring in the past affected equally the catchability of the commercially-important species and winter skate. Clearly in the absence of data on catchability or gear selectivity, little can be done to assess or correct this. The assumption also implies that the bycatch rate of winter skate is not dependent on the type of fishery, i.e., the weight of winter skate captured per kg of American plaice is the same whether the fisher was targeting plaice or targeting another species and capturing plaice incidentally. If bycatch rates are indeed dependent on the fishery type, then the assumption implies that the proportion of landings across the various fisheries (i.e., directed versus mixed fisheries) for a commercially-important species should have been constant over time. Unfortunately, little can be done to correct for such past problems.

Estimating southern Gulf winter skate discards, including error propagation

Error propagation is the calculation of statistical error in a quantity that constitutes the end point of a number of intermediate steps, each with its associated error. Bootstrapping computer simulations are an effective manner to estimate errors of complex quantitites (e.g., Blukacz et al. 2005). Bootstrap simulations can either be parametric, with observations drawn from a probability distribution, or non-parametric, where raw observations are sampled randomly with replacement, for example (Efron and Tibshirani 1993). Given the large sample sizes generally available for the various data inputs to the calculation of winter skate discards and an *a priori* lack of information on the appropriate parametric probability distributions to use, non-parametric bootstrapping was employed throughout the calculations.

The steps involved in calculating total annual winter skate discards are summarized in Fig. 1, where boxes represent input data. Data from a series of research vessel bottom-trawl surveys conducted at different times of the year during the late 1980s and early 1990s (Table 2; see also Darbyson and Benoît (2003) for details on the surveys) are used to estimate the conditional probability of catching a winter skate given than any skate is captured, as a function of depth and by season (step 1):

$$\ln[\frac{p_{i,s}}{1-p_{i,s}}] = \beta_{s0} + \beta_{s1} \bullet depth$$

where the left-hand side of the equation is the logit transformation of $p_{i,s}$, the proportion of skates captured in survey set *i* in season *s*. To capture the error inherent in these empirical relationships, the individual survey sets within each season during each bootstrap simulation were sampled with replacement prior to calculating the logistic regressions. The seasonal logistic regression parameter estimates were then considered as representative of the mid-point of all the surveys conducted in each season. Parameters for the empirical relationships for other months were then linearly interpolated from these “seasonal” estimates (step 2; see *Results* for a better description and justification of this approach).

Three different versions of winter skate discards were calculated for this report: based only on catches of fish called *winter skate* by at-sea observers (termed “*observed winter skate*” hereafter), based on those catches in addition to a proportion of skates identified only at the Family-level by observers and finally based on a proportion of all skates caught. In the case of the latter two quantities, the proportion was estimated for each fishing set as a function of depth and month using the empirical relationships from step 2. Calculated discards based on observed winter skate only are clearly underestimated and should not be used in any assessment of winter skate population dynamics. Discard estimates that use the empirical models to predict the catch of winter skate from the catch of all skates are likely most appropriate for population assessment as they include both a proportion of the unidentified skates and make corrections for skates that appear to be misidentified.

Once the catches of winter skate were predicted, they were summed by fishing trip, as were the catches of each of the eleven commercially important species (step 3). Fishing trip was used as the sampling unit as this is the level at which observers are deployed and for which landings information is generally recorded. Because the deployment of observers in the Gulf has generally been non-random with respect to all fishing trips, post-stratification was used to reduce any resulting biases (*H.P. Benoît and J. Allard, in prep.*). Stratification was based on fleet (ITQ vs. competitive), fishery and province. Mean annual bycatch rates of winter skate were then calculated for each of the eleven commercially-important species (step 5):

$$B_{iy} = \sum_{j=1}^{F_y} \sum_{k=1}^{f_{iy}} \sum_{l=1}^{p_{ijy}} \frac{\sum_{m=1}^{n_{jkly}} \left(\frac{W_{jklmy}}{\sum_{i=1}^{11} O_{ijklmy}} \right)}{n_{jkly}} \cdot \frac{C_{ijkly}}{\sum_{j=1}^{F_y} \sum_{k=1}^{f_{iy}} \sum_{l=1}^{p_{ijy}} C_{ijkly}}$$

where B_{iy} is the catch of winter skate per unit catch of commercially-targetted species i (i.e., $kg \cdot kg^{-1}$) in year y, W_{jklm} is the total catch of winter skate (kg) by fleet j, in fishery k, province l and trip m, O_i is the total catch (kg) of i as recorded by the at-sea observers, C_i is the total landings (kg) for that species, n is the total number of trips in the stratum, p is the number of provinces, f is the number of fisheries and F is the number of fleets in the fishery . In other words, for a given year, the bycatch rate for species i is the mean of stratum-specific winter skate bycatch rates, each weighted by the proportion of total landings of i made in that stratum. Bootstrapping was undertaken by sampling trips at random with replacement from within each year and stratum.

For the 1991-2004 period, the mean annual bycatch rates for each of the eleven species were multiplied by the respective total annual landings (step 6a) and then summed across the eleven species to arrive at a final estimate of total winter skate discards (step 7). Because the total landings represent a complete census, they were assumed to be known without error. Total discards for the 1971-1990 period were calculated using an average bycatch rate for each of the eleven landed species based the 1991-1993 bycatch rates (step 6b). This average was used, rather than one based on the full 1991-2004 data, because it was presumed to be more representative of the bycatch rates of the 1970s and 1980s given that it covers a period of comparably high fishing effort for most fisheries. In contrast, observer data over the remaining 1994-2004 period include years of moratoria for cod, white hake and redfish that would not be representative of past conditions.

The discards estimated in steps 6b and 7 assume that estimated bycatch rates over the period 1971-1990 were insensitive to any changes in the relative abundance of winter skate and each of the landed species. As noted in the previous section, research survey data on relative abundance was used to correct the bycatch rates for such changes (see Hurlbut and Clay (1990) and Benoît & Swain (2003a,b) for details on the southern Gulf of St. Lawrence multi-species bottom-trawl survey methodology and the data, respectively). In order to capture the observation error associated with abundance indices estimated from the survey, sets were sampled at random with replacement from within each year and survey stratum during each bootstrapping simulation. Catches from repeated sets made at a single location in a given year (see Benoît and Swain (2003b) for details) were averaged prior to re-sampling the sets. The mean weight (kg) captured per tow was then estimated for each species using the standard method for stratified sampling (Krebs 1989). These mean catches were used to calculate a catch rate (e.g., kg winter skate per kg cod, in the survey) for each commercial species and year in the period 1971-1993 (step 8). Individual catch rates from 1971-1990 were then divided by the mean survey catch rate for 1991-1993 to obtain a relative catch ratio for each landed species and year. The relative catch ratios were then multiplied by the total winter skate discards estimated in step 7 to obtain relative-abundance-corrected discard estimates (step 9).

One thousand bootstrap simulations were used to estimate the median winter skate discards levels and associated error. This number of simulations was sufficient to capture the error in the final estimates, as stable estimates of central tendency and relative variability were obtained within 500-700 iterations (Figure 2).

RESULTS

Are winter skate properly identified by at-sea observers?

In the southern Gulf of St. Lawrence in September, winter skate are generally found in shallow waters, based on research surveys (Fig. 3; see also Darbyson and Benoît (2003) and Clay (1991)). During the late fall, winter skate move off shore and become much more broadly distributed across the area over the winter. The distribution is still relatively broad in the spring (April/May), though slightly more concentrated in shallow waters compared to the winter. By July-August, winter skate are further concentrated in shallow waters, though not to the extent observed in September.

Although a concentration of winter skate catches in waters <50m reported by observers in September suggests that some observers are properly identifying the species, numerous reports of catches in deeper waters (>200m) in July-September are inconsistent with survey data and suggest misidentification (Fig. 3). With a few exceptions, winter skate are reported by observers roughly in proportion to the number of sets capturing any skate, regardless of species. This suggests that a number of observers may not be accurately distinguishing between skate species.

Estimating the conditional probability of capturing winter skate given that any skate is caught

There were sufficient data to model the probability of capturing winter skate, conditional on having captured a skate of any species (*P(winter skate*| *any skate is captured)*), for four "seasons" in the southern Gulf of St. Lawrence: spring (based on surveys from April-May), summer (July-August), fall (September) and winter (late November-early January) (Table 2). Although surveys have been conducted in other months (details in Darbyson and Benoît, 2003), the total number of sets capturing skates or the range of depths sampled were too small to properly estimate the conditional probability as a function of depth.

Logistic regression analysis was used to model the conditional probability as a function of depth. The results from an analysis including the covariate *depth*, the factor '*season*' and their interaction, confirmed that the depth distribution of winter skate relative to other skates in the southern Gulf varies significantly seasonally ($p<0.0001$ for the interaction term; Table 3). Consequently, separate models were estimated for each season (Fig. 4). Depth significantly affects the conditional probability of capturing winter skate in all seasons (Table 4). A series of models, each including various degree polynomials for depth were considered to test if a nonlinear relationship between conditional probability and depth might provide a better fit to the data (Table 5). The Akaike Information Criterion (AIC), which evaluates the negative log-likelihood fit of a model to the data while penalizing for the number of parameters estimated, was used to quantify model suitability. In all seasons, the model including only a linear term for depth was found to be most parsimonious (Table 5).

Although only four sets of logistic regression parameters were estimated over the annual seasonal cycle, they appear to follow a cyclic pattern that captures the nearshore-offshore movement of winter skate: a relatively shallow and negative slope and small intercept in the spring, a steepening slope and generally increasing intercept through the summer and into the fall, followed by a decreasing slope and intercept into the early winter (Fig 5a). Given the need to predict the conditional probability of capturing winter skate in months other than those for which a model was estimated when calculating discard amounts, slope and intercept parameters of the logistic regression were linearly interpolated from the mid-points of adjacent "seasonal" surveys. Linear interpolation was used given the small number of parameter sets available over the seasonal cycle and an inability to estimate reliably a more complex cyclic model for slope and intercept. Given the roughly similar time interval between adjoining seasonal survey midpoints (Fig 5a), linear interpolation reasonably approximates such a cyclic model (Fig 5b).

Because the seasonal surveys were conducted during a relatively restricted number of years, generally outside the period in which they are being applied in estimating discards (1991-2004), it was necessary to assess whether the bathymetric distribution of winter skate relative to other skates is consistent from year to year. Large changes in the distribution of thorny skate (Swain and Benoît, 2006) and a contracting distribution for winter skate from 1985-2002 (Benoît et al., 2003a) further motivate such an assessment. Using the September research survey data, 1971-2004, and adding the covariate *year* to the logistic regression as a function of depth, I tested for inter-annual changes in the bathymetric distribution of winter skate relative to other skates. The interaction between *depth* and *year* was not statistically significant (P=0.0836, Table 6) indicating that the slope relating the conditional probability of catching winter skate did not change linearly (or monotonically) over time. When the interaction term was removed from the model, the effect of *year* was statistically significant, though very small compared to seasonal differences in bathymetric distribution (Table 6; Fig. 4). Given the small interannual differences observed for September over a relatively large period of time (1971-2004), it was assumed that the parameters of the logistic regression models for the other seasons can be applied across years.

When, where and how are winter skate captured in Gulf of St. Lawrence commercial fisheries?

For this subsection only, observer data from throughout the Gulf of St. Lawrence, collected by the observer companies Biorex (covering the Maritime provinces and Québec) and Seawatch (Newfoundland), are presented to provide a better overview of when, where and how winter skate are captured. The remainder of the document concentrates on the data collected by observers that are relevant to the southern Gulf of St. Lawrence winter skate designateable unit, namely those from NAFO division 4T.

Most fishing activities in the Gulf of St. Lawrence take place between April and December (Fig 6) and are generally preempted by sea ice conditions in other months. Winter skate are captured throughout the fishing season, although they appear to be caught more frequently in the late spring and in the fall relative to the total number of finfish and shrimp fishing sets covered by observers. The largest amounts of “observed” winter skate are reported in September-October, whereas large total catches of skates predicted to be winter skate are reported in the late spring in addition to the fall. The most frequent and largest catches occur in the southern Gulf of St. Lawrence (NAFO division 4T) (Fig. 6). Although they are captured widely in the southern Gulf, catches are particularly concentrated in unit areas 4Tf, 4Tg and 4Tm (Fig. 7). Winter skate are captured much less frequently in fisheries in the northeastern Gulf of St. Lawrence (NAFO 4R), and even less so in the northwestern Gulf (NAFO 4S) (Fig. 6).

For “observed” winter skate, captures are reported most frequently in the winter flounder, cod, Greenland halibut and shrimp fisheries, though relative to the total number of observed sets, they are mostly concentrated in the winter flounder fishery (Fig. 6). Relative to the total number of observed sets, they are captured mostly by bottom trawls, followed by gillnets and shrimp trawls. For skates predicted to be winter skate, captures are reported most frequently in the cod, witch flounder, American plaice and winter flounder fisheries, and are most concentrated in the latter two. Most catches are reported from bottom trawl and demersal seine (Scottish or Danish) fisheries, and much less frequently in hook-and-line, gillnet and shrimp fisheries.

Assumptions involved in inferring winter skate discard levels

As stated previously, inferring discard levels using bycatch rates (kg per kg landed species) assumes that catches of the incidentally captured and landed species are proportional (Rochet and Trenkel, 2005). Any strong departures from this assumption (i.e., a non-linear relationship) would result in biased discard estimates. Although the catches of the incidentally captured and targeted species do not appear linearly related in the data collected by observers in the southern Gulf of St. Lawrence, there seem to be no indications of a non-linear relationship either (Fig. 8). As a result the use of mean bycatch rates, as was done in calculating total discards, should provide unbiased estimates overall even though the assumption of proportionality is not met. Indeed, inferring winter skate discard levels using bycatch rates produces estimates that are very similar in magnitude and trend to those obtained using catch per trip, for those fisheries where both types of data were available since 1991 (Fig. 9). Although the latter discard estimates are favored on theoretical grounds (Rochet and Trenkel, 2005) and seem less prone to some large year-to-year fluctuations (e.g., 1997 and 2001-2002 in Fig. 9b,c), using bycatch rates to estimate total discards in the absence of long-term data on individual fishing trips appears to be reasonable.

Bycatch rates of winter skate were generally positively correlated between research surveys and commercial fisheries for the majority of the commercially landed species, though statistically significantly so in only two cases (Table 7). However, correlations were often weak, and occasionally negative, providing only weak support for the assumption of a positive relationship between survey and commercial bycatch rates. This assumption is required if the survey data are to be used to correct estimated bycatch rates for past changes in the relative abundance of winter skate and the landed species. A lack of contrast in this relative abundance over the 1991-2004 period, differences in when and where commercial and scientific fishing take place and a possible non-linear relationship between survey and commercial bycatch rates are all plausible explanations for the weak correlations observed. In the absence of strong evidence to the contrary, a linear relationship between survey and commercial bycatch rates was assumed when prorating past bycatch rates (steps 8-10, Fig. 1), although the resulting discard estimates should be interpreted in light of the weak support of the assumption of proportionality.

Estimated winter skate discard levels, 1971-2004

Discard estimates based only on catches of winter skate reported by observers were the lowest of the three different estimates (Fig. 10a), and likely represent an underestimate as they do not include the non-negligible proportion of skate observations made at the Family level only (Table 1). Estimated median catches of winter skate varied between sixty and one-hundred and sixty tonnes from 1971-1991, dropping considerably thereafter to ten tonnes or less in all but one year (Appendix I). Adding the proportion of unspecified skates predicted to be winter skate based on their depth distribution increases the estimated catch levels ~2.5 fold, thought the overall trend remains the same (Fig. 10b). Discard estimates based on the predicted proportion of all skates reported by observers are approximately five to six times greater than those based on reported catches of winter skate, at about 500 tonnes through to 1990, falling to an average of about fifty tonnes during the 1990s and generally under ten tonnes in the 2000s (Fig. 10c, Appendix I). A single large catch of unspecified skates predicted to be winter skate in the cod fixed gear fishery in 1999 resulted in an unusually high estimated median catch level with very high uncertainty around it (Fig. 10c, Appendix I, 1999a). Removing this fishing set from the calculation resulted in a median estimate and associated uncertainty level that are in-line with those from neighboring years (Appendix I, 1999b). For the three sets of discard estimates presented in Appendix I, confidence intervals generally range from half to twice the median value for the lower and upper intervals respectively.

Correcting for changes in the relative abundance of winter skate and landed species prior to 1991 increases considerably the estimated discard levels during the 1970s and into the 1980s (Fig. 10, Appendix II). Estimated median catches of “observed” winter skate varied generally between 150-300 tonnes in most years from 1971-1988, peaking at close to 1,000 tonnes in 1979. Adding the proportion of unspecified skates predicted to be winter skate based on their depth distribution increases the estimated median catch levels by ~2-3 fold through much of the 1970s and by ~1.5 fold throughout much of the 1980s (Fig. 10b). Discard estimates based on the predicted proportion of all skates reported by observers, with corrections for changes in relative abundance, were at their highest level in 1971 (about 2,000 tonnes) and generally declined over time to about 100 tonnes by the early 1990s and under fifty tonnes after 2000 (Fig. 10c). Confidence intervals for discard estimates corrected for changes in relative abundance range from about half to more than twice the median value for the lower and upper intervals respectively. The greater relative uncertainty associated with the discard estimates corrected for changes in relative abundance compared to uncorrected estimates reflects the observation error associated with the research survey species abundance estimates.

Estimated discard levels based only on catches of winter skate reported by observers were associated mainly with catches of cod, Greenland halibut, American plaice, and to a lesser extent witch and winter flounder (Fig. 11a). The association with Greenland halibut is considerably greater, over 1971-1990, when corrections for relative abundance are applied (Fig. 11b), reflecting the dramatic changes in that species' abundance observed in the southern Gulf research survey (Benoît et al., 2003a). Overall, a large proportion of the estimated 1991-2004 discards come from fixed gear fisheries (Fig 12a).

Discard levels estimated from observed winter skate plus a predicted proportion of unspecified skates show a similar association as in Figs. 11a,b to particular landed species, though they were more strongly associated with cod catches (Fig. 11c,d). Although the proportion of those estimated discards coming from fixed gear fisheries is considerably smaller (Fig 12b).

In slight contrast to the other two cases, discard levels estimated from the predicted proportion of all skates reported by observers were most associated with cod, followed by American plaice and winter flounder, but only very little with Greenland halibut (Fig 11e,f). They were also further associated with mobile gear fisheries, particularly those for American plaice, winter and yellowtail flounders, and cod (Fig. 12c).

Potential survival of discarded winter skate

Overall, median estimated bycatch levels for winter skate were generally an order of magnitude larger than the reported landings of all (unspecified) skates in the southern Gulf of St. Lawrence (Fig. 13). Given that catches of thorny skate probably comprise a large proportion of these landings based on the relative prevalence of the respective skate species in fishery catches (Table 1), these data suggest that most winter skate bycatch is discarded at sea in most years. However, little is known about the eventual survival of these winter skate.

Only two studies have examined the mortality of discarded skates, and in both cases only acute, short-term, mortality (i.e., within hours of capture) was assessed. Stobutzki et al. (2002) studied the within-net survival of a number of ray species in an Australian prawn trawl fishery and estimated an acute mortality of about 56%. Mortality was highest for smaller individuals and males. Laptikhovsky (2004) estimated an acute mortality of about 40% across seven ray species in a squid bottom-trawl fishery off the Falkland Islands, again with a higher susceptibility of males. Delayed mortality associated with injury or disease, or increased predation risk resulting from behavioural impairment (Davis, 2002) was not assessed in these studies.

In an effort to better estimate the potential survival of discarded southern Gulf of St. Lawrence skates, the acute mortality of winter, thorny and smooth skate was studied during the 2005 annual research survey. Because the survey was undertaken by two research vessels as part of an inter-calibration study, the skate study was done on both vessels. Regular survey fishing and sample processing procedures were followed (see Hurlbut and Clay, 1990), however survey technicians included an assessment of whether or not skate were respiring, by examining their spiracles for 10 seconds for signs of ventilation, as part of the detailed sampling (i.e., length, weight, gender, maturity) of individual skate. The time at which the detailed sampling took place was also noted, allowing for the calculation of the approximate amount of time the skate were out of water prior to being assessed for signs of respiration. (The calculation is considered approximate because it does not take into account the time required to haul the trawl from the bottom to the ocean's surface, which would vary from under five minutes in shallow water to 15 minutes in the deepest waters). Because this study was incorporated into the regular survey sampling and because it included rapid and non-destructive observation, no significant additional mortality of skate was inflicted above what occurs during typical research surveys.

The proportion of skate not respiring was modeled using a stepwise logistic regression that was a function of two factors, *species* (thorny, smooth or winter skate) and *gender* (male, female), and four covariates: approximate *time out of water* (0.6-3.9 hrs), fishing *depth* (22-337 m), skate body *length* (9-67 cm) and total catch *biomass* in the trawl tow (18-816 kg). The complete model potentially included these effects along with all possible linear interactions. The stepwise forward selection process retained only four effects that significantly explained variation in the probability that a skate was not respiring: *time out of water*, *body length*, the interaction of these two effects and *species* (Table 8). Unlike Stobutzki et al. (2002) and Laptikhovsky (2004), skate *gender* was not a statistically significant effect. To ensure that the significance of the *species* effect was not a spurious result of the small number of winter skate included in the analysis (25 individuals), the analysis was repeated, excluding that species. The *species* effect remained significant, confirming that for a given body *length* and *time* out of water, thorny skate have a slightly higher survival rate than smooth skate.

Because the survival of winter skate relative to the other species could not be reliably estimated, a species aggregated relationship should be used for that species (Fig. 14a). The fit of that model was greatest for smaller lengths, likely due in part to the larger sample size available (Fig. 15). For the majority of skates captured during the survey, 50% of individuals had ceased respiring after spending 1-2 hours out of water (Fig. 14b). This time interval roughly corresponds to the median catch handling time of commercial groundfish trawlers on the Scotian Shelf in 1987, as reported in Neilson et al (1989). It is reasonable to assume that handling times for Gulf of St. Lawrence trawlers would have been comparable over the 1971-1993 period, when groundfishery catches were high. This would suggest an acute mortality rate of skate of at least 50%. If the lower groundfish catches during the 1994-2004 period were accompanied by shorter handling times, the rate would have been lower. However, overall the actual acute mortality rate may be underestimated given that commercial mobile gear fishing sets are generally of longer duration than research sets (1-4 vs. 0.5 hours) (e.g., Olla et al. 1997). Furthermore, long-term mortality resulting from injuries sustained during the fishing operations is likely higher than the acute estimate (Davis 2002). While the acute mortality of winter skate in fixed gear fisheries may be lower because of considerably shorter handling times, the injuries sustained may be more severe (e.g., torn mouth part in long-line fishing sets, *personal observation*) resulting in a delay in mortality compared to fish captured in mobile gear. Overall, given the results presented here and in Stobutzki et al. (2002) and Laptikhovsky (2004), and given that the majority of winter skate catches are made in mobile-gear fisheries, a discard mortality rate of at least 50% should be assumed.

CONCLUSIONS

Overall, based on the most realistic assumptions regarding winter skate bycatch, total levels on the order of 2,000 tonnes were estimated for 1971, declining over time to about 100 tonnes by the early 1990s and under fifty tonnes in the 2000s. Although most of these skate would have been discarded at sea, estimates of a less than 50% survival suggest a potentially non-negligible fishery-induced mortality of winter skate (although the population-level mortality rate depends on total abundance and is the focus of another document (Swain et al. 2006)).

Estimating discards by extrapolating at-sea fishery observations to entire fishing fleets involves a suite of assumptions about how the data are collected, how they can be raised to obtain total estimates in the years observations are made and how they can be extrapolated to the past. In addition, correcting problems with the taxonomic identification of skates by observers required making further assumptions about the distribution of winter skate relative to other skates.
The validity of these assumptions was evaluated to the extent possible so as to keep known biases to a minimum and incorporated any associated error into the final discard estimates. Nonetheless, violations of the assumptions of a random or systematic deployment of observers to fishing trips, changes in fisher behaviour when observers are on board (*H.P. Benoît and J. Allard, in prep.*) and a possible non-linear relationship between species relative abundance and catch rates (Rochet and Trenkel, 2005) can result in biased discard estimates. The magnitude of that bias is not known.

ACKNOWLEDGEMENTS

I thank Doug Swain for numerous insightful discussions over the course of preparing this document and Tobie Surette for his helpful review of the document. Many thanks also to the scientific crew and students aboard the *CCGS Teleost* and *CCGS Alfred Needler* during the 2005 research survey for collecting the data on acute skate mortality.

REFERENCES

Benoît, H.P., M.-J. Abgrall, and D.P. Swain. 2003a. An assessment of the general status of marine and diadromous fish species in the southern Gulf of St. Lawrence based on annual bottom-trawl surveys (1971-2002). Can. Tech. Rep. Fish. Aquat. Sci. **2472**: 183 pp.

Benoît, H.P., E. Darbyson and D.P. Swain. 2003b. An atlas of the geographic distribution of marine fish and invertebrates in the southern Gulf of St. Lawrence based on annual bottom trawl surveys (1971-2002). Can. Data Rep. Fish. Aquat. Sci. **1112**: 185 p.

Benoît, H.P. and D.P. Swain. 2003a. Accounting for length and depth-dependent diel variation in catchability of fish and invertebrates in an annual bottom-trawl survey. ICES Journal of Marine Science **60**: 1297-1316.

Benoît, H.P. and D.P. Swain. 2003b. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: adjusting for changes in research vessel, gear and survey protocol. Can. Tech. Rep. Fish. Aquat. Sci. no. **2505**: iv + 95 pp

Blukacz, E.A., W.G. Sprule and J. Brunner. 2005. Use of the bootstrap for error propagation in estimating zooplankton production. Ecology **86**: 2223-2231.

Clay, D. 1991. Seasonal distribution of demersal fish (Osteichthyes) and skates (Chrondrichthyes) in the southeastern Gulf of St. Lawrence. *In* The Gulf of St. Lawrence: small ocean or big estuary? Edited by J.-C. Therriault, Can. Spec. Publ. Fish. Aquat. Sci. **113**: 241–259.

COSEWIC 2005. COSEWIC assessment and status report on the winter skate Leucoraja ocellata in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vii + 41 pp.

Darbyson, E., and H.P. Benoît. 2003. An atlas of the seasonal distribution of marine fish and invertebrates in the southern Gulf of St. Lawrence. Can. Data Rep. Fish. Aquat. Sci. **1113**: 294 p.

Davis, M.W. 2002. Key principles for understanding fish bycatch discard mortality. Can. J. Fish. Aquat. Sci. **59**:1834-1843.

Efron, B., and R. Tibshirani. 1993. An Introduction to the Bootstrap. Chapman and Hall, N.Y.

Hurlbut, T., and D. Clay. 1990. Protocols for research vessel cruises within the Gulf region (demersal fish) (1970-1987). Can. Manuscr. Rep. Fish. Aquat. Sci. **2082**: 143 p.

Laptikhovsky, V.V. 2004. Survival rates for rays discarded by the bottom trawl squid fishery off the Falkland Islands. Fish. Bull. **102**:757-759.

Neilson, J.D., K.G. Waiwood and S.J. Smith. 1989. Survival of Atlantic halibut (Hippoglossus hippoglossus) caught by longline and otter trawl gear. Can. J. Fish. Aquat. Sci. **46**: 887-897.

Olla, B.L., M.W. Davis, and C.B. Schreck. 1997. Effects of simulated trawling on sablefish and walley Pollock: the role of light intensity, net velocity and towing duration. J. Fish. Biol. **50**: 1181-1194.

Rochet, M.-J., and V.M. Trenkel. 2005. Factors for the variability of discards: assumptions and field evidence. Can. J. Fish. Aquat. Sci. **62**: 224-235.

Scott, W.B., and Scott, M.G. 1988. Atlantic Fishes of Canada. Can. Bull. Fish. Aquat. Sci. **219**: 731 p.

Stobutzki, I.C., M.J. Miller, D.S. Heales and D.T. Brewer. 2002. Sustainability of elasmobranchs caught as bycatch in a tropical prawn (shrimp) trawl fishery. Fish. Bull. **100**: 800-821.

Swain, D.P., and H.P. Benoît. 2006. Changes in habitat associations and geographic distribution of thorny skate (*Amblyraja radiata*) in the southern Gulf of St. Lawrence: density-dependent habitat selection or response to environmental change? Fish. Oceanog. 15: 166-182

Swain, D.P., T. Hurlbut and H.P. Benoît. 2005. Changes in the abundance and size of skates in the southern Gulf of St. Lawrence, 1971-2002. J. Northwest. Atl. Fish. Sci. **36**: 19-20.

Swain, D.P., Jonsen, I., R.A. Myers. 2006. Recovery potential assessment of 4T and 4VW winter skate (Leucoraja ocellata): population models. DFO Can. Sci. Advis. Sec. Res. Doc. 2006/004.

Table 1. Frequency of capture and total catch (kg) of skates during commercial fishing activities in the Gulf of St. Lawrence (NAFO 4RST) covered by at-sea observers, 1990-2004. Thorny, smooth and winter skates commonly occur in the Gulf of St. Lawrence, whereas barndoor and spinytail skates are thought to occur much less frequently based on research surveys. All other skate and manta species reported by the observers were considered to be misidentified. There are likely also a large number of records where skates were mistaken for another of the common species in the area (see text), although this is not reflected in this table which tabulates only what was reported by observers. Finally, a large number of records were reported only for the Family level, as "unspecified" skates.

	Number of sets			Total observed catch (kg)		
NAFO Division:	4R	4S	4T	4R	4S	4T
Barndoor skate (*Dipturus laevis*)	3	14	18	32	101	185
Thorny skate (*Amblyraja radiata*)	1,193	6,112	9,452	18,030	71,359	229,231
Smooth skate (*Malacoraja senta*)	150	768	1,043	743	3,191	9,435
Winter skate (*Leucoraja ocellata*)	14	96	477	141	1,267	4,518
Spinytail skate (*Bathyraja spinicauda*)	208	720	842	2,620	6,731	13,390
Unspecified	1,961	1,794	5,272	40,383	15,718	154,107
Misidentified	6	94	82	56	233	2,033

Table 2. Seasonal and September research survey data used in estimating the seasonal depth distribution of winter skate (WS).

Survey	Dates	Area surveyed	Number of bottom-trawl sets
Spring surveys:			
Lady Hammond 172	May 19-24,1987	Southeastern Gulf	43
CCGS A. Needler 151	Apr. 18-28, 1991	Southwestern and south-central Gulf	85
		Sets with WS:	78
Summer surveys:			
Lady Hammond 215	Jun. 29-Jul. 6, 1990	Southwestern and south-central Gulf	70
Lady Hammond 245	Aug. 01-08, 1992	Southwestern and south-central Gulf	68
		Sets with WS:	9
Fall surveys:			
Lady Hammond 159, 179,192,204	Sept. 1986, 1987, 1988, 1989	southern Gulf (NAFO 4T)	1162
		Sets with WS:	181
Winter surveys:			
Lady Hammond 166	Dec. 04-09, 1986	Southeastern Gulf	34
CCGS A. Needler 073	Jan. 07-10, 1987	Southeastern Gulf	23
Lady Hammond 209	Dec. 01-07, 1989	Southwestern Gulf	24
Lady Hammond 223	Nov. 20-28, 1990	Southwestern and south-central Gulf	79
		Sets with WS:	98

Table 3. Results of a Type III analysis of effects from the logistic regression model,
Logit(P(winter skate|a skate is captured))$=\alpha+\beta_1\cdot depth+\beta_2\cdot season+\beta_3\cdot depth*season+\varepsilon$

Effect	DF	Wald Chi-Square	Pr > ChiSq
depth	1	88.0853	<.0001
season	3	45.1814	<.0001
depth*season	3	191.9476	<.0001

Table 4. Results of logistic regression analyses by season using the model,
Logit(P(winter skate|a skate is captured))$=\alpha+\beta_1\cdot depth+\varepsilon$

Season	R^2	Parameter	DF	Estimate	Standard Error	Wald Chi-Square	Pr > ChiSq
Spring	0.33	α	1	2.1878	0.4096	28.5292	<.0001
		β_1	1	-0.0265	0.00412	41.2350	<.0001
Summer	0.54	α	1	2.1121	0.5850	13.0343	0.0003
		β_1	1	-0.0766	0.0130	34.5792	<.0001
Fall	0.46	α	1	3.9890	0.3011	175.4797	<.0001
		β_1	1	-0.1120	0.00749	223.1892	<.0001
Winter	0.09	α	1	1.4412	0.3009	22.9424	<.0001
		β_1	1	-0.00729	0.00155	22.0547	<.0001

Table 5. Akaike Information Criteria for seasonal logistic regression models including various degrees of a polynomial for depth(m),

i.e., $Logit(\ P(\text{winter skate}|\ \text{a skate is captured})) = \alpha + \beta_1 \cdot depth + \beta_2 \cdot depth^2 + \ldots + \beta_n \cdot depth^n + \varepsilon$

Season	Polynomial 1rst degree	 2nd degree	 3rd degree	 4th degree
Spring	182.8	195.8	200.2	200.5
Summer	95.7	99.2	107.0	108.3
Fall	929.8	939.7	942.2	944.0
Winter	266.7	274.9	290.4	290.8

Table 6. Results of logistic regression analyses based on the September research survey data, 1971-2004.

Model	R^2	Parameter	DF	Estimate	Standard Error	Wald χ^2	Pr> χ^2
$Logit(\ P(\text{winter skate}|\ \text{a skate is captured})) = \alpha + \beta_1 \cdot depth + \beta_2 \cdot year + \beta_3 \cdot depth*year + \varepsilon$							
	0.559	α	1	-13.3241	41.3368	0.1039	0.7472
		β_1	1	1.6998	1.0459	2.6414	0.1041
		β_2	1	0.0086	0.0208	0.1729	0.6776
		β_3	1	-0.0009	0.0005	2.9927	0.0836
$Logit(\ P(\text{winter skate}|\ \text{a skate is captured})) = \alpha + \beta_1 \cdot depth + \beta_2 \cdot year + \varepsilon$							
	0.558	α	1	54.5561	12.7557	18.2927	<.0001
		β_1	1	-0.1099	0.0041	703.6531	<.0001
		β_2	1	-0.0255	0.0064	15.8470	<.0001

Table 7. Spearman rank correlations between annual catch rates of skate (kg / kg of commercial species) in observed commercial fishing sets and in the September research survey, 1991-2004. Correlations in bold print were significant at the α=0.05 level.

Commercial species	*Observed winter skate*	*Observed + proportion (unident. skates)*	*Predicted proportion (all skates)*
Cod	0.53	-0.09	0.18
White hake	0.38	-0.02	-0.09
Redfish	0.47	**0.59**	0.41
Atlantic halibut	0.09	0.25	0.07
Greenland halibut	0.06	0.01	0.09
Plaice	0.01	0.02	0.01
Witch flounder	**0.73**	-0.21	-0.21
Yellowtail flounder	0.23	0.09	0.19
Winter flounder	0.30	0.30	0.32
Spiny dogfish	0.05	-0.04	-0.24
Shrimp	-0.34	-0.31	0.30

Table 8. Results of a stepwise forward-selection logistic regression model of the probability that a skate was not respiring when sampled. Four hundred and thirty skates were sampled (323 thorny skate, 82 smooth skate and 25 winter skate), of which 216 were classified as not respiring. The complete model potentially included factors for *species* (thorny, smooth or winter skate) and *gender* (male, female), the covariates *time* (decimal hours elapsed from the end of the trawl tow to the biological sampling), fishing *depth* (meters), skate body *length* (cm) and total catch *biomass* in the trawl tow (kg), along with all possible interactions. Only the results for those factors and covariates selected by the analysis are presented here.

a) Analysis including all three species of skates: $R^2_{\text{Max-rescaled}}$ =0.43

Type 3 Analysis of Effects

Step	***Effect***	***DF***	***Wald*** χ^2	***Pr >*** χ^2
1 -	time	1	37.4054	<.0001
2 -	length	1	5.9122	0.0150
3 -	time · length	1	15.2461	<.0001
4 -	species	2	9.8976	0.0071

Analysis of Maximum Likelihood Estimates

Parameter	***DF***	***Estimate***	***S.E.***	***Wald*** χ^2	***Pr >*** χ^2
intercept	1	-7.3482	1.4017	27.4808	<.0001
time	1	6.5526	1.0714	37.4054	<.0001
length	1	0.0834	0.0343	5.9122	0.0150
time · length	1	-0.0971	0.0249	15.2461	<.0001
species* (thorny skate)	1	-0.3996	0.2491	2.5737	0.1087
species* (smooth skate)	1	0.5724	0.2725	4.4131	0.0357

** the effect of species is relative to winter skate*

b) Analysis excluding winter skate: $R^2_{\text{Max-rescaled}}$ =0.41

Type 3 Analysis of Effects

Step	***Effect***	***DF***	***Wald*** χ^2	***Pr >*** χ^2
1-	time	1	37.5483	<.0001
2-	length	1	8.3501	0.0039
3-	time*length	1	17.4336	<.0001
4-	species	1	10.3581	0.0013

Analysis of Maximum Likelihood Estimates

Parameter	***DF***	***Estimate***	***S.E.***	***Wald*** χ^2	***Pr >*** χ^2
intercept	1	-7.8916	1.4777	28.5196	<.0001
time	1	7.0029	1.1428	37.5483	<.0001
length	1	0.1066	0.0369	8.3501	0.0039
time*length	1	-0.1130	0.0271	17.4336	<.0001
species (thorny skate)	1	-0.4973	0.1545	10.3581	0.0013

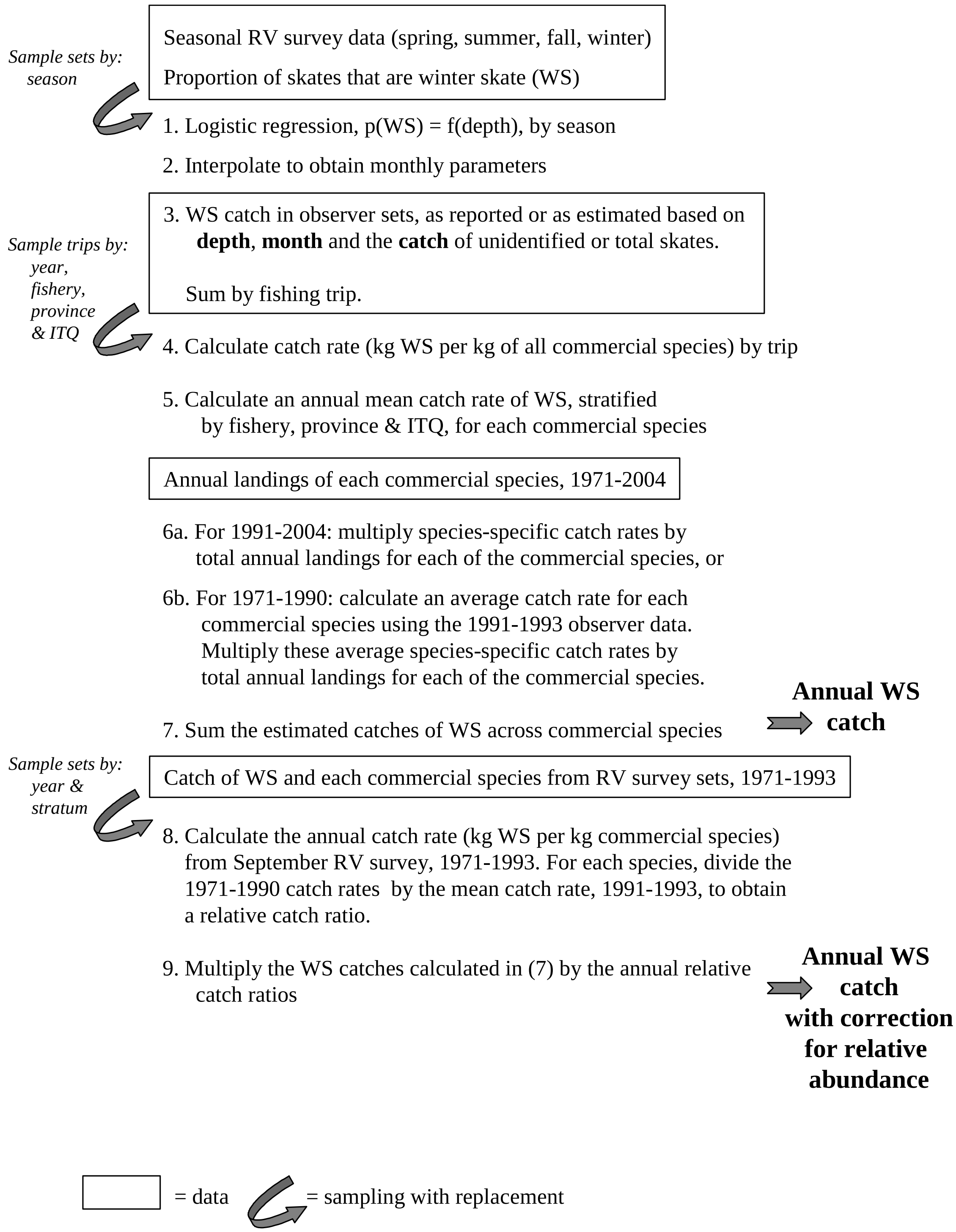

Figure 1. Flow chart of the steps involved in estimating winter skate discards using bootstrapping simulations. Boxes represent data inputs and curved arrows indicate steps involving sampling with replacement.

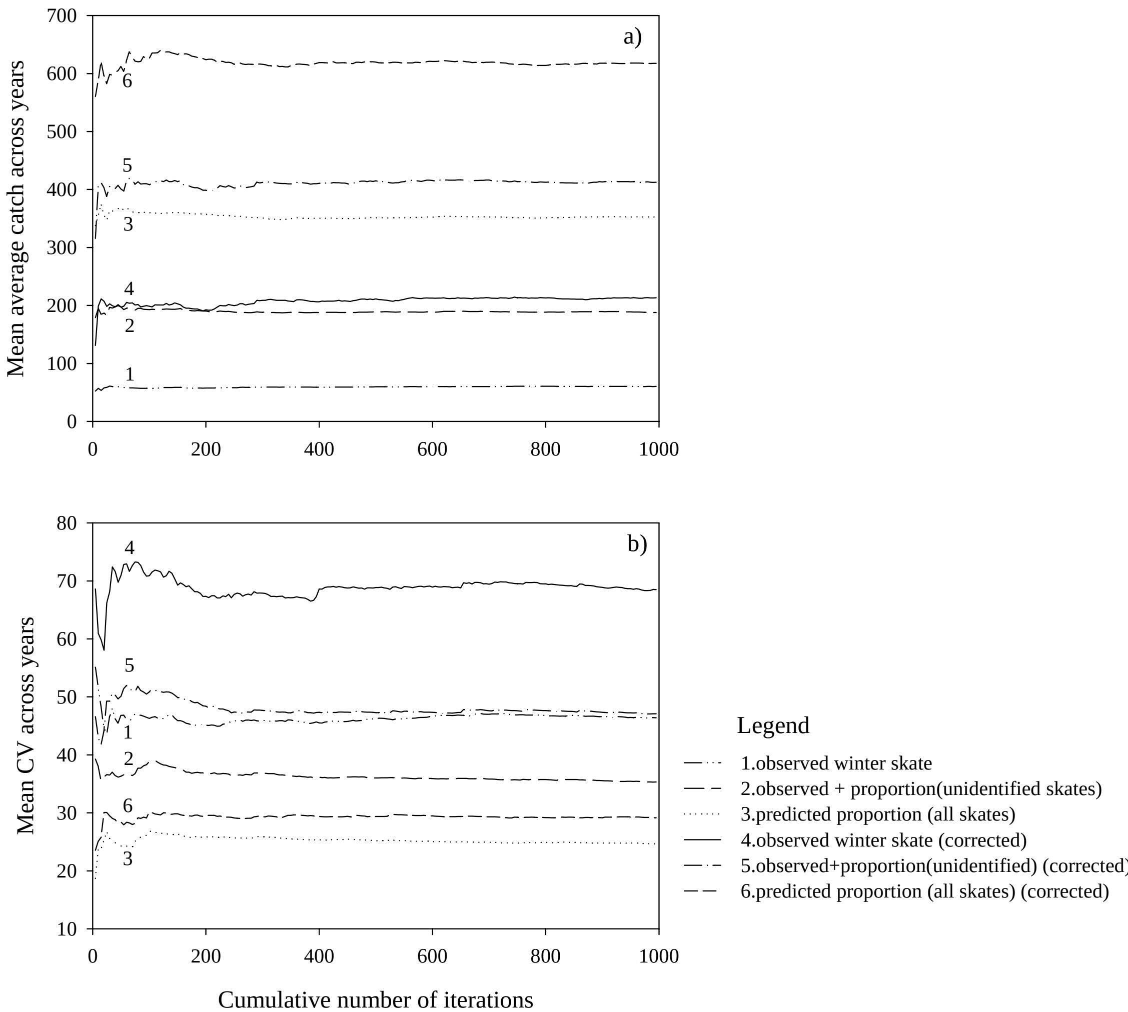

Figure 2. Results of simulations to assess the number of bootstrapping iterations required to appropriately estimate (a) the average discard levels and (b) their associated variability. Simulations were run for the three different winter skate discard estimates (i.e., based on observed winter skate only, based on observed winter skate plus a proportion of unidentified skates and based on an estimated proportion of all skates) and with or without corrections for relative abundance during 1971-1991.

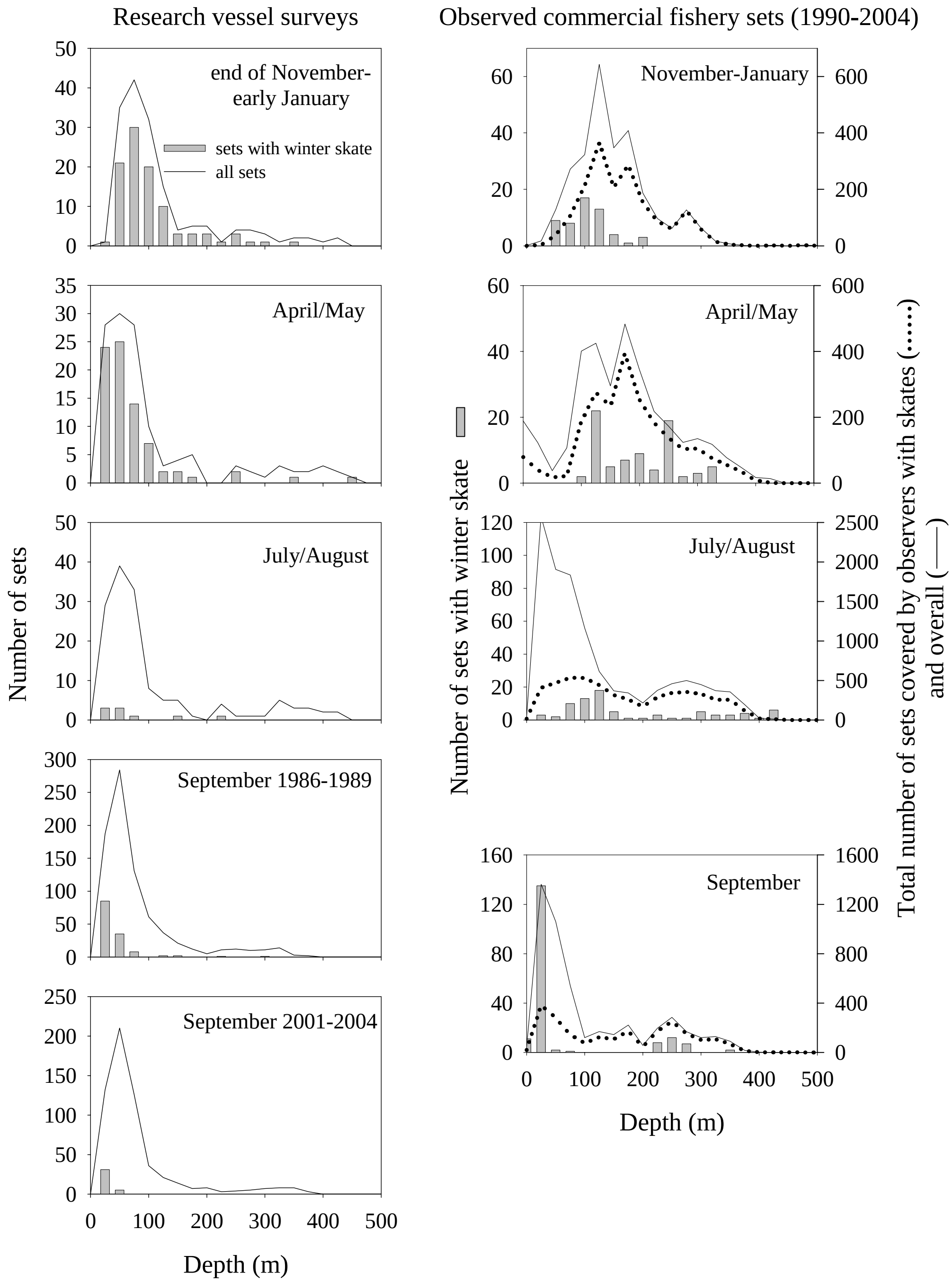

Figure 3. Total number of fishing sets and sets catching winter skate as a function of depth (m) from research vessel surveys (left column) and in observed commercial fishery sets (right column) by season (rows). Plots for observed commercial fishery sets are for fish reported as winter skate by observers and also include the total number of sets in which skates of any species were reported.

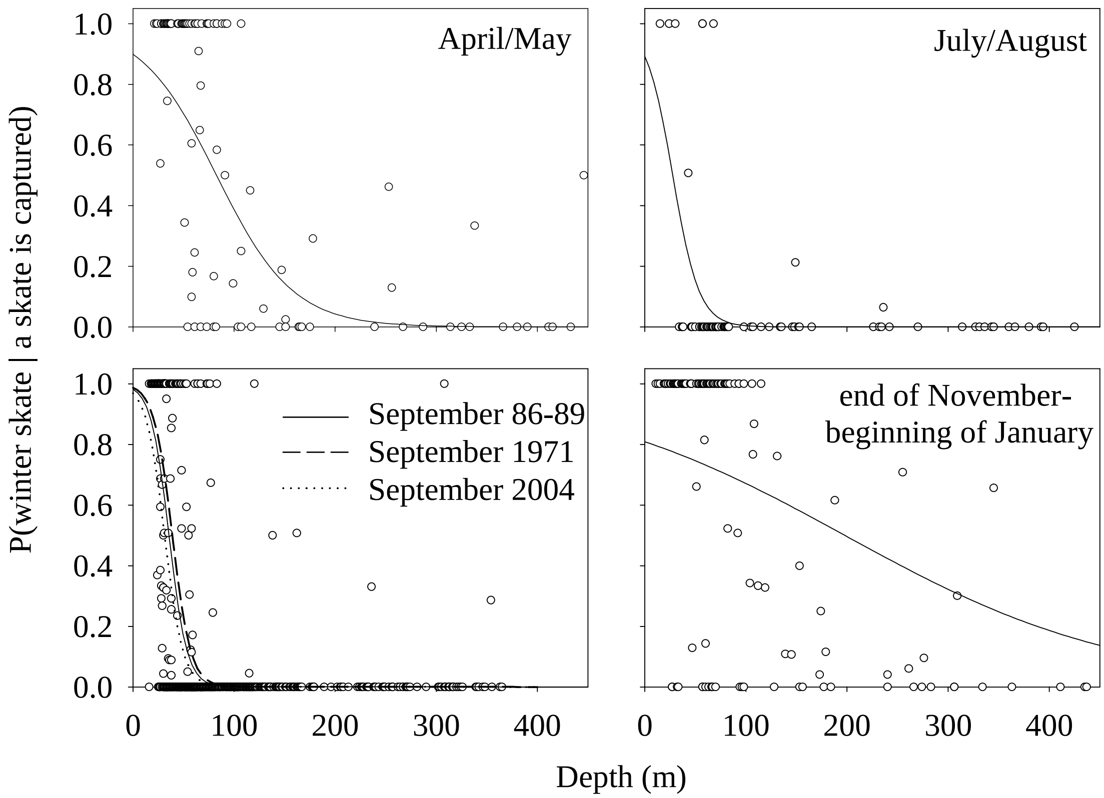

Figure 4. Fits of seasonal logistic regression models of the conditional probability of capturing winter skate, given that a skate of any species is captured, as a function of depth. The plot for September includes the observed and predicted conditional probability as a function of depth for September 1986-1989, as well as the predicted relationships for 1971 and 2004 (see Table 6) to highlight the low degree of interannual variability.

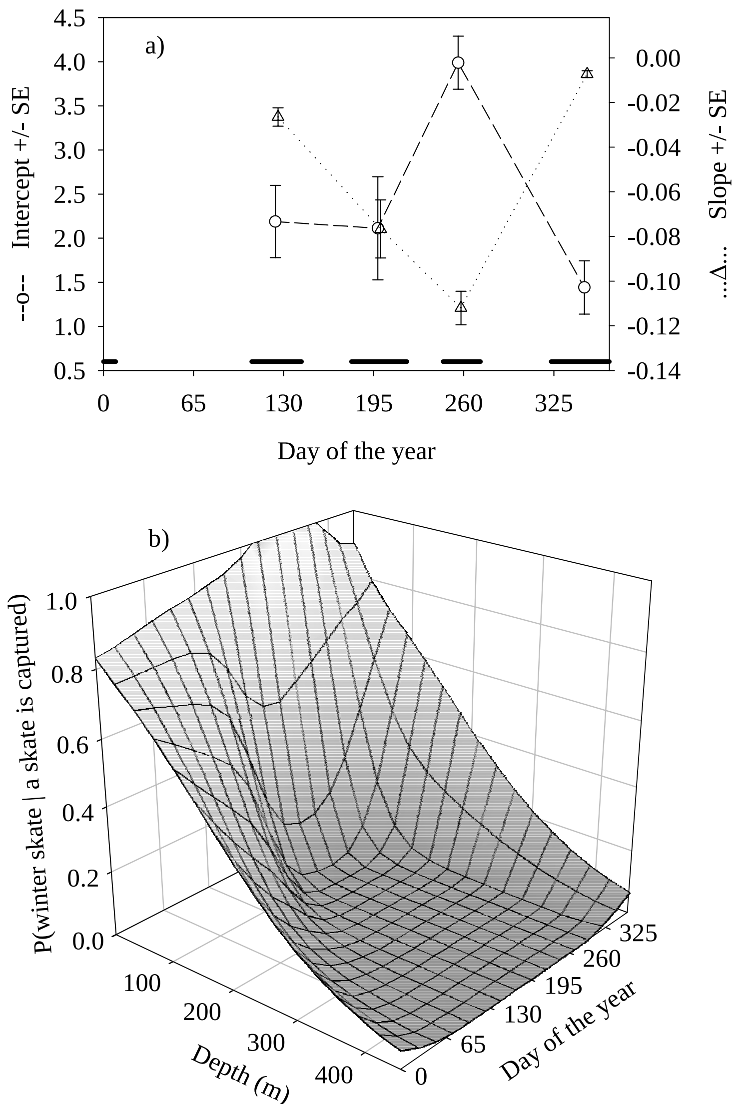

Figure 5. a) Parameter estimates (intercept and slope, with standard error) for the logistic regression models describing the conditional probability of capturing winter skate as a function of bottom depth (m). Parameter estimates are plotted at the mid point of the seasonal surveys from which they were calculated. The time span of those surveys is indicated by the bold lines at the bottom of the plots. The parameter estimates were linearly interpolated to predict parameter values in neighboring months and ultimately (b) the conditional probability of capturing winter skate as a function of bottom depth throughout the annual cycle.

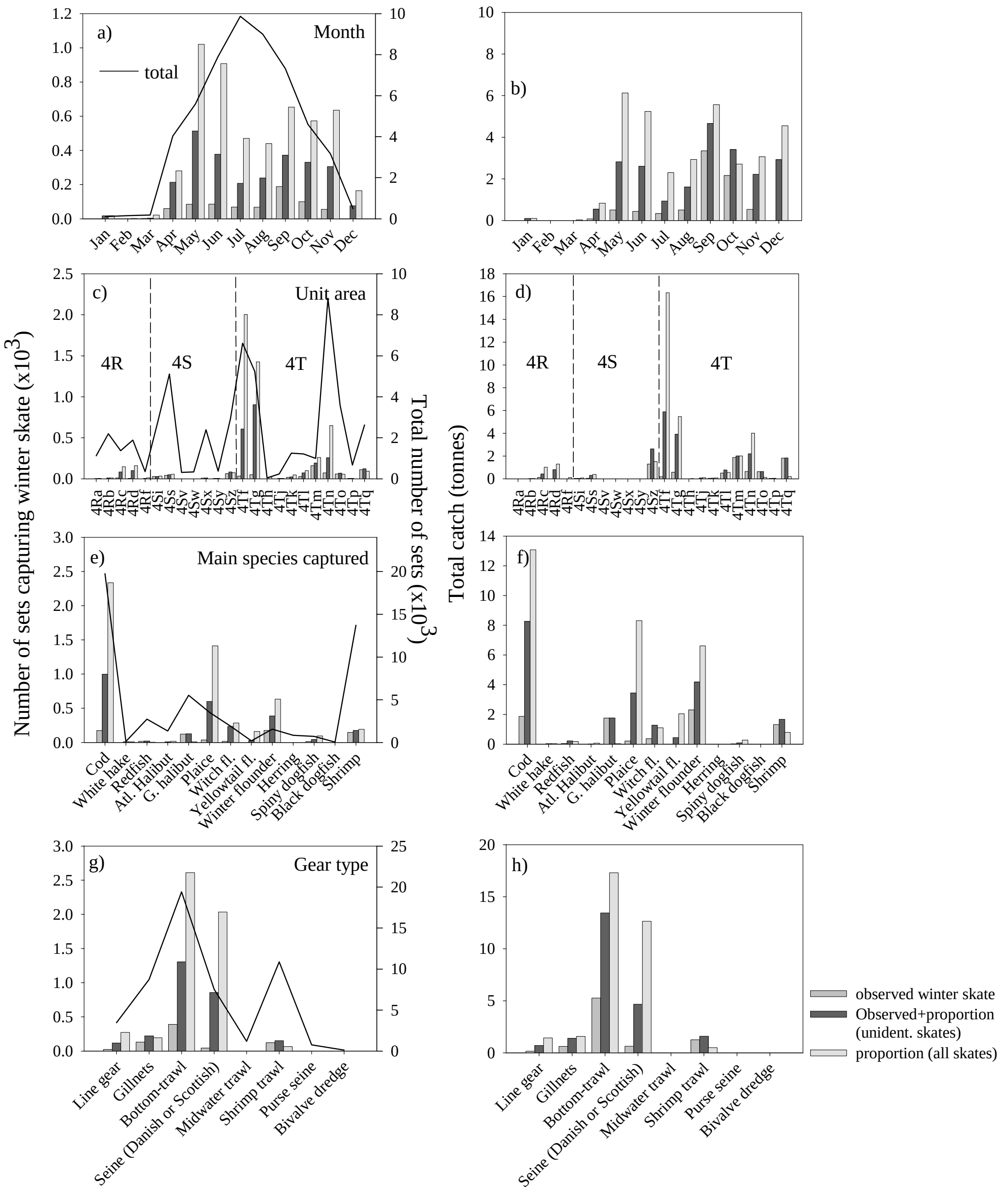

Figure 6. Total number of fishing sets in the Gulf of St. Lawrence covered by observers and total sets capturing winter skate (left column), and total catch of winter skate (right column), by month (*panels* a, b), unit area (c, d), main species captured (e, f) and fishing gear type (g, h). Numbers are presented for observed winter skate, observed winter skate plus a proportion of unidentified skates and for winter skate predicted based on an estimated proportion of all skates.

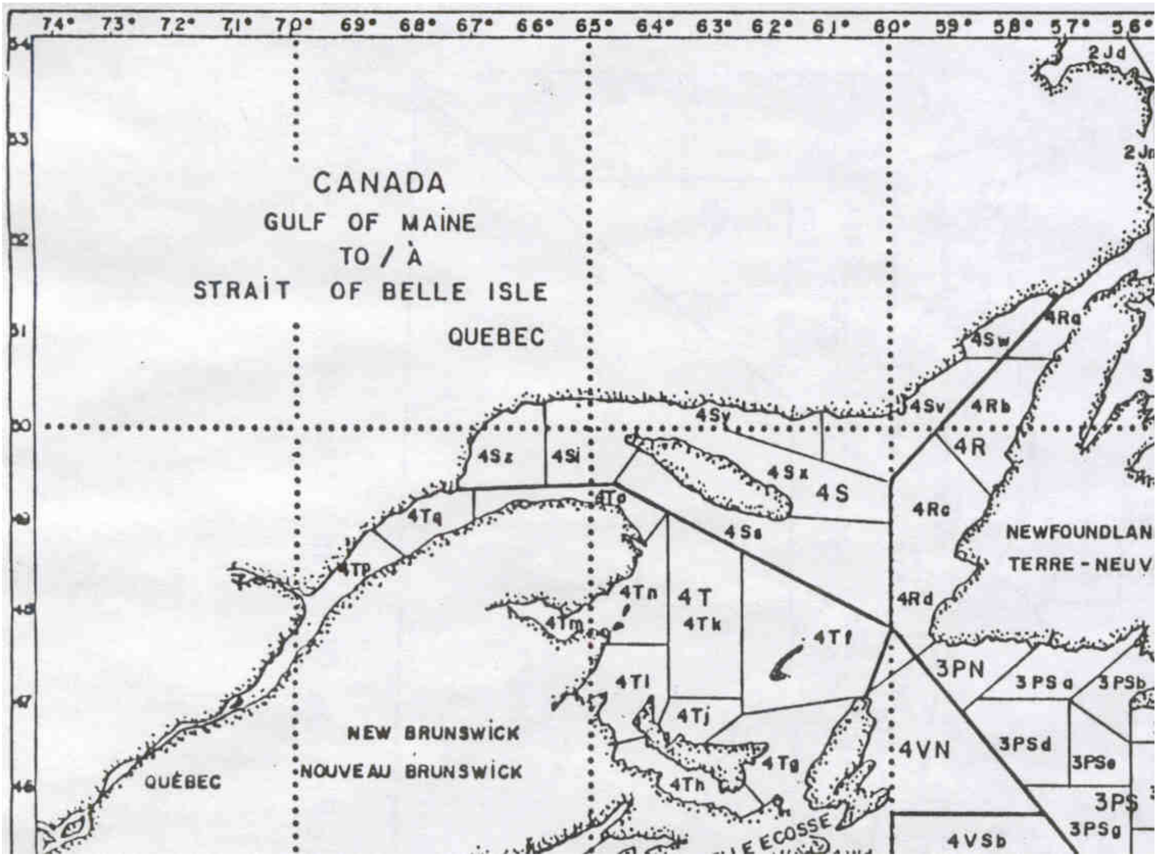

Figure 7. Northwest Atlantic Fisheries Organization (NAFO) unit areas of the Gulf of St. Lawrence and neighboring areas.

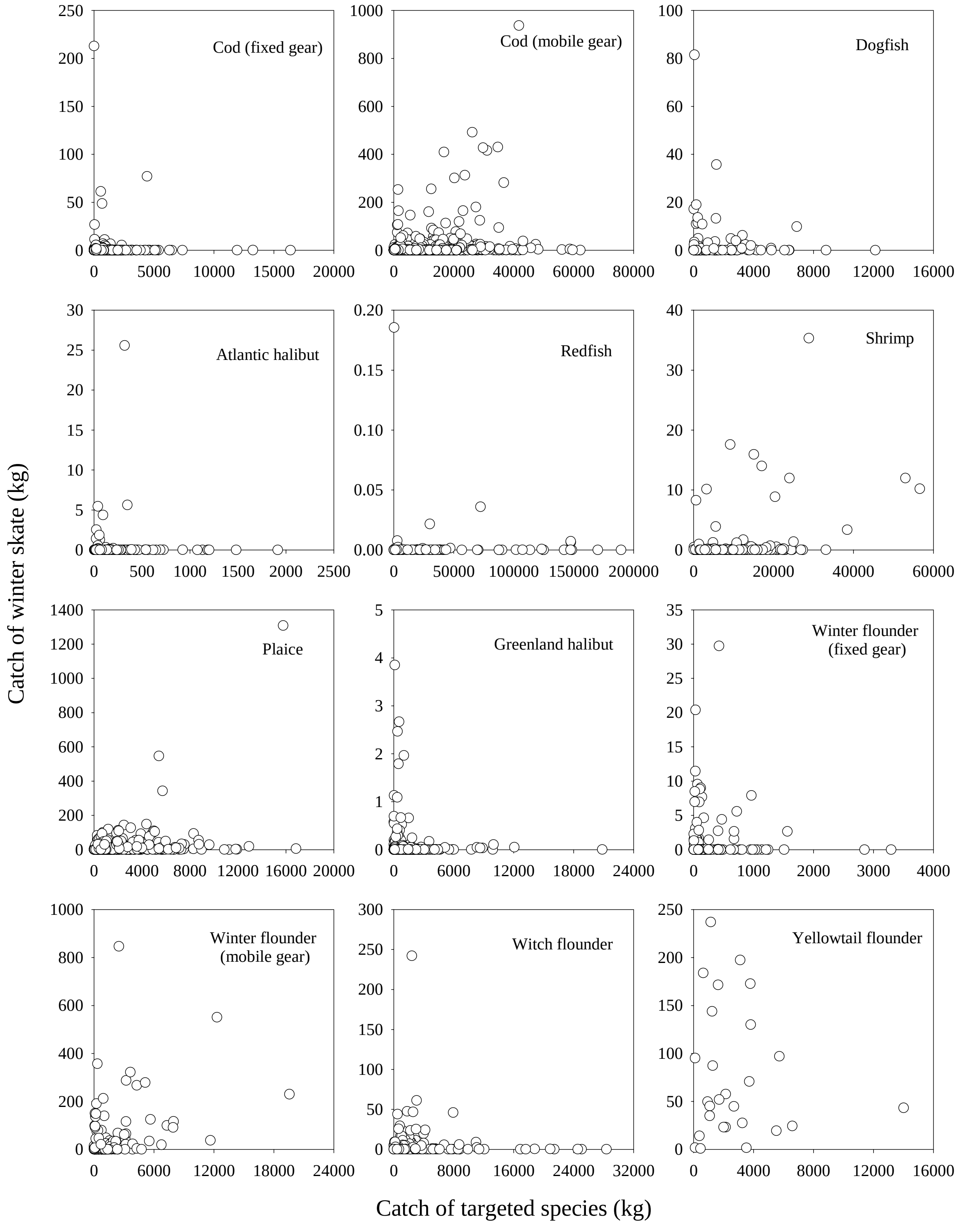

Figure 8. Catch of winter skate (predicted as a proportion of the catch of all skates) as a function of the catch of the targeted species, by fishing trip, in twelve groundfish fisheries covered by at sea observers.

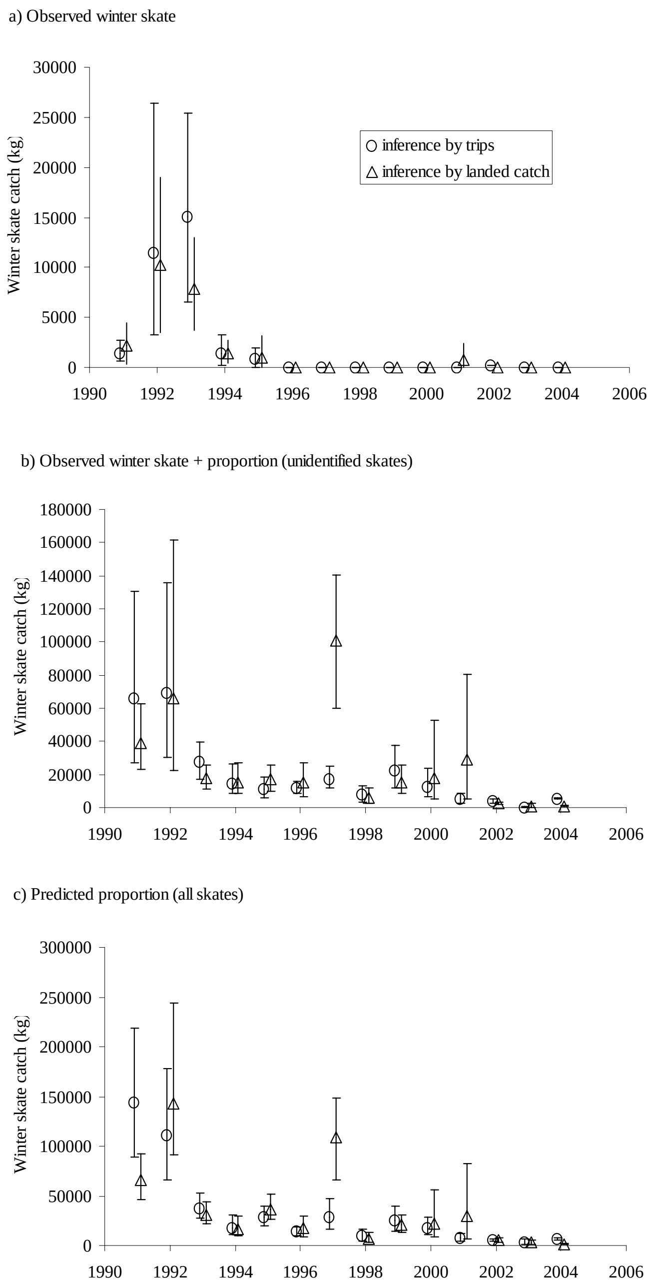

Figure 9. Comparison of total winter skate discards (median ± 90% C.I.) inferred from catches per observed fishing trips and inferred from bycatch rates, for estimates based on (a) observed winter skate only, (b) based on observed winter skate plus a proportion of unidentified skates and (c) based on winter skate predicted as a proportion of all skates.

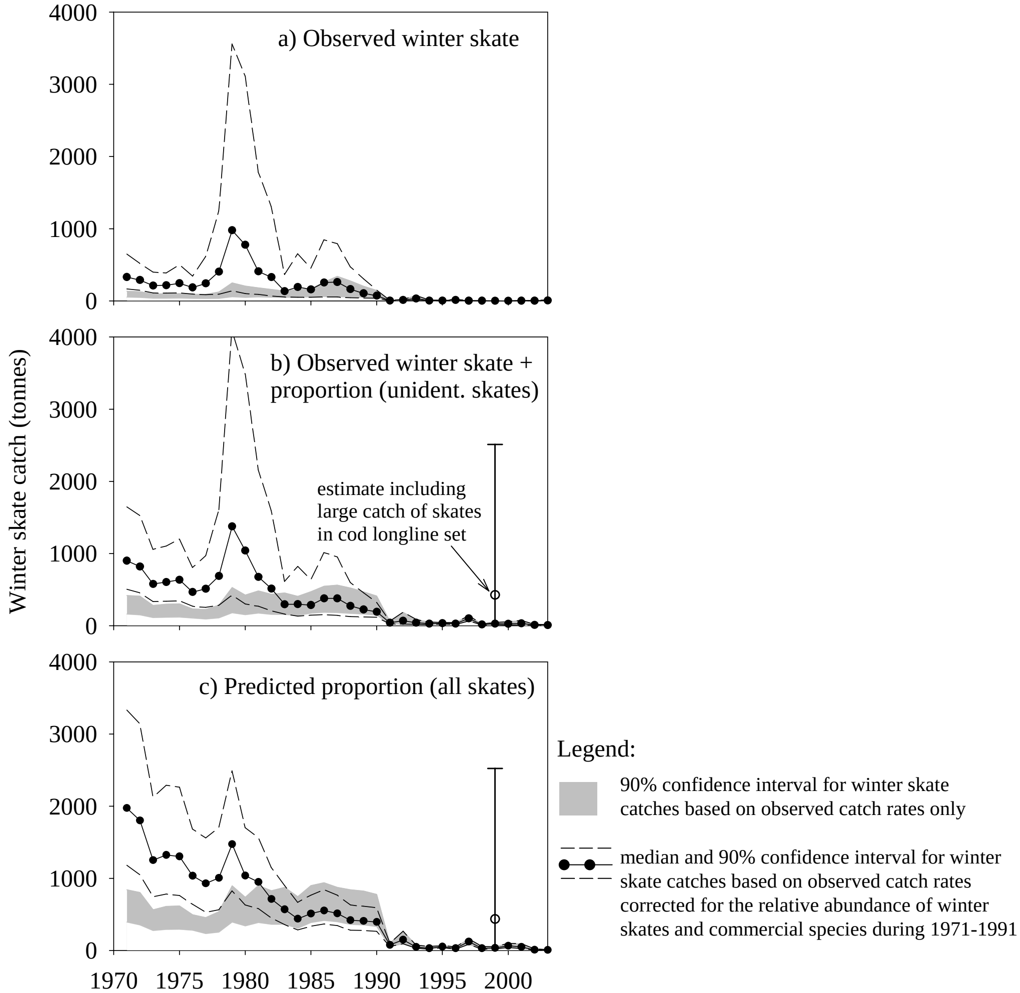

Figure 10. Total winter skate discards in the southern Gulf of St. Lawrence, 1971-2004, based on 1000 bootstrapping simulations and estimated with (lines) and without (shaded area) a correction for changes in the relative abundance of species over the period 1971-1991. Estimates are provided based on (a) observed winter skate only, (b) based on observed winter skate plus a proportion of unidentified skates and (c) based on winter skate predicted as a proportion of all skates. For clarity, only the 90% confidence interval is plotted for the estimates without a correction for relative abundance (see Appendix I for median values). Estimates including and excluding an observed large set of skates predicted to be winter skate in 1999 are presented in panels b and c.

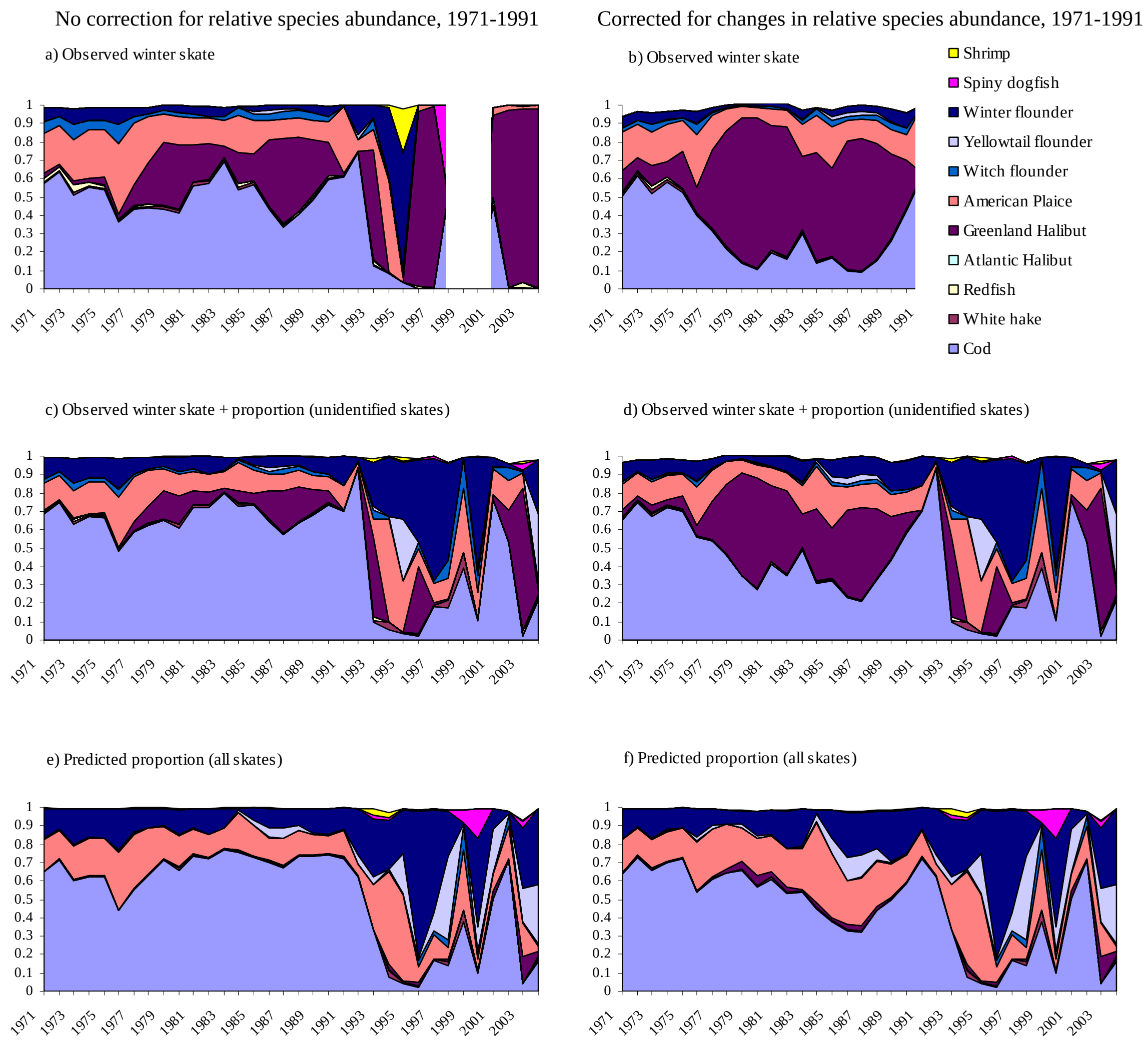

Figure 11. Proportion of total winter skate bycatch associated with each of the commercially-important species, 1971-2004, without (left column) and with (right) corrections for changes in the relative abundance of species over the period 1971-1991. Plots are for winter skate catch estimates based on observed winter skate only (panels a and b), based on observed winter skate plus a proportion of unidentified skates (c, d) and based on winter skate predicted as a proportion of all skates (e, f). The observed large set of skates predicted to be winter skate in the cod fixed gear fishery in 1999 was excluded from the analysis. Note that panel (b) is terminated in 1991 as patterns after that date are identical to those in (a) and to allow placement of the legend. Note also that proportions in all panels do not necessarily add to exactly 1 as they are a mean of bootstrap simulations.

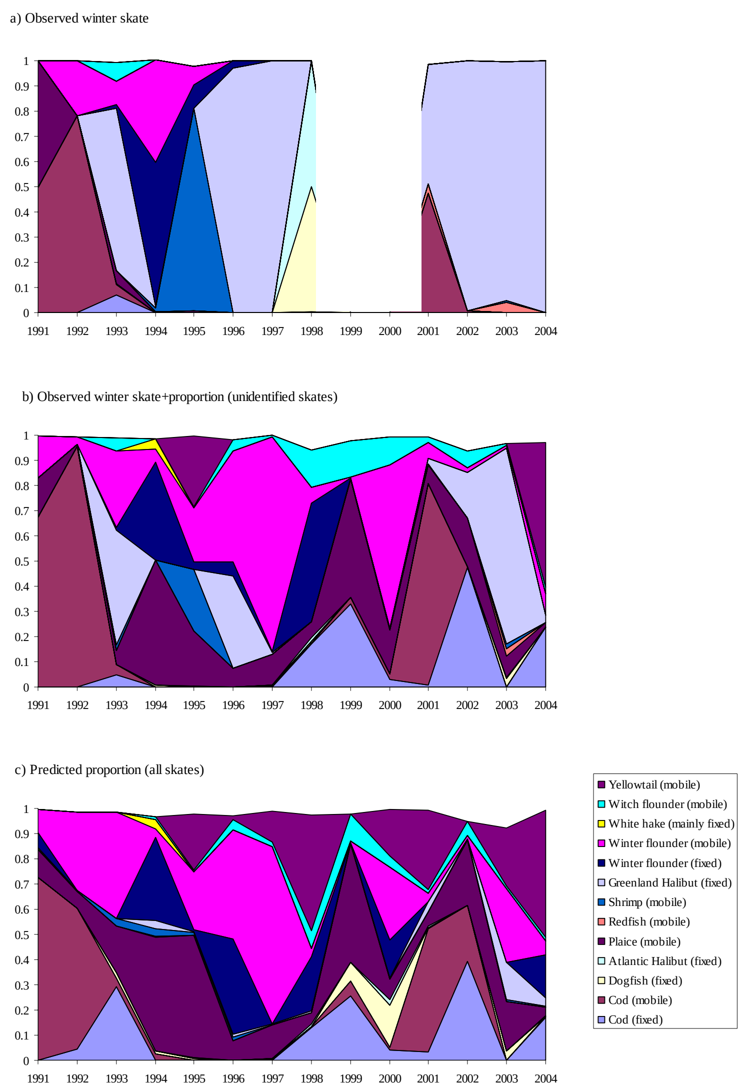

Figure 12. Proportion of total winter skate bycatch associated with each of the fisheries, 1991-2004, for winter skate catch estimates based on (a) observed winter skate only, (b) based on observed winter skate plus a proportion of unidentified skates and (c) based on winter skate predicted as a proportion of all skates. The observed large set of skates predicted to be winter skate in the cod fixed gear fishery in 1999 was excluded from the analysis. Note that proportions in the panels do not necessarily add to exactly 1 as they are a mean of bootstrap simulations.

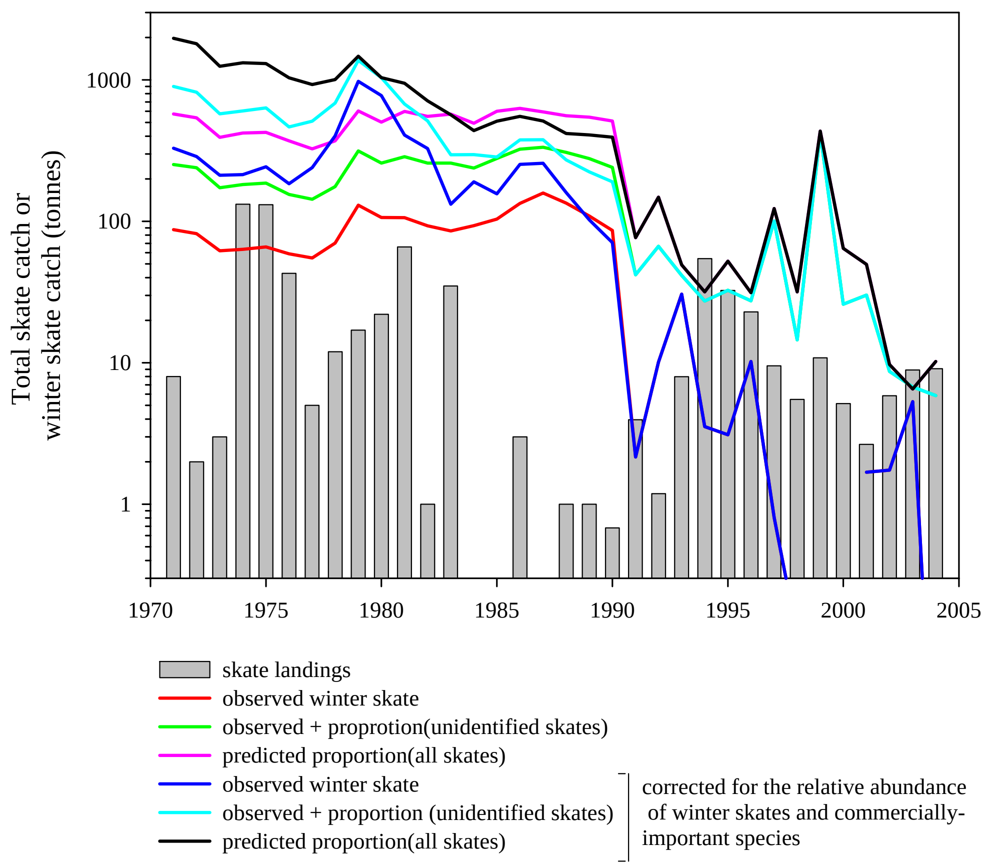

Figure 13. Total skate landings and median estimated winter skate discards (see Appendices I and II) in the southern Gulf of St. Lawrence, 1971-2004.

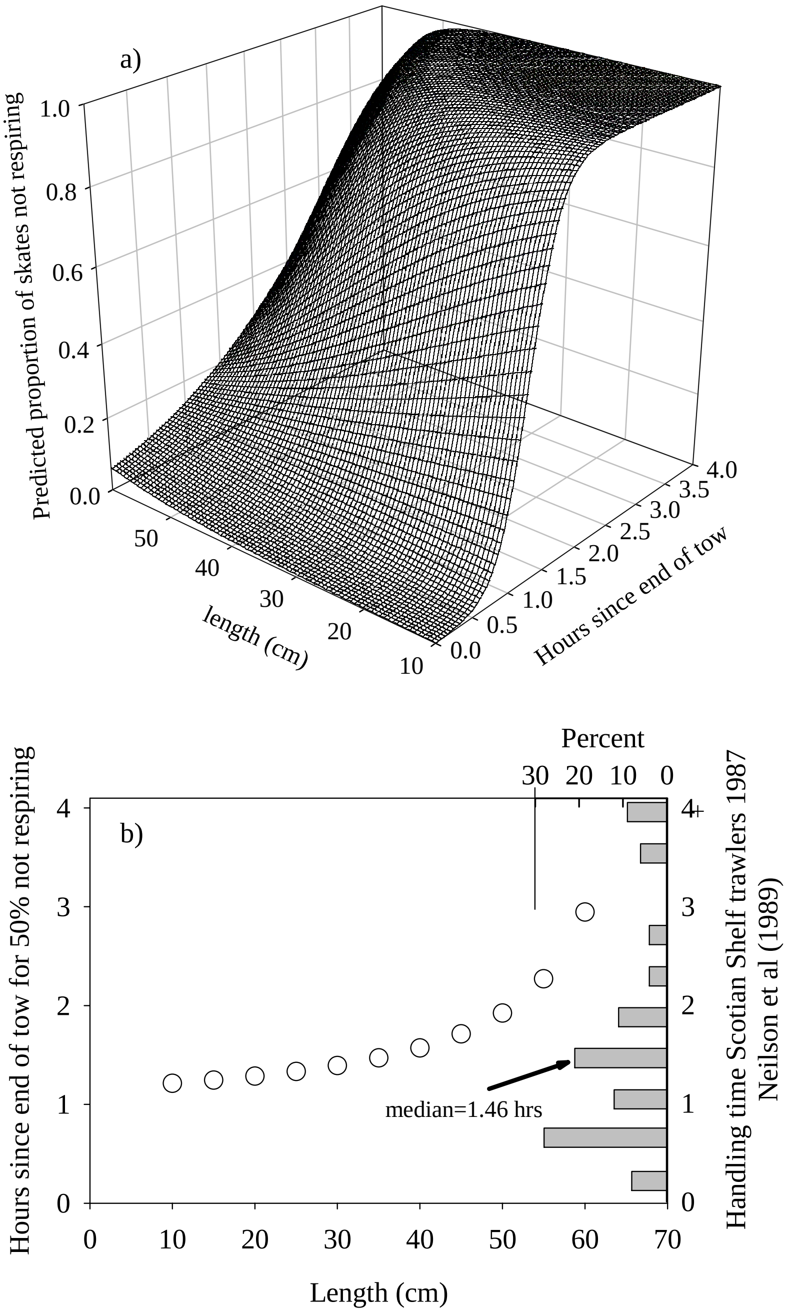

Figure 14. a) Estimated proportion of skates not respiring as a function of the time elapsed since the end of the tow and body length for a logistic model that did not include the effect of species. b) Predicted number of hours elapsed since the end of the tow required for 50% of skates to not be respiring, as a function of body length. The inset on the right shows the distribution of fish catch handling times for the Scotian Shelf bottom-trawl fleet in 1987 (from Neilson et al. 1989).

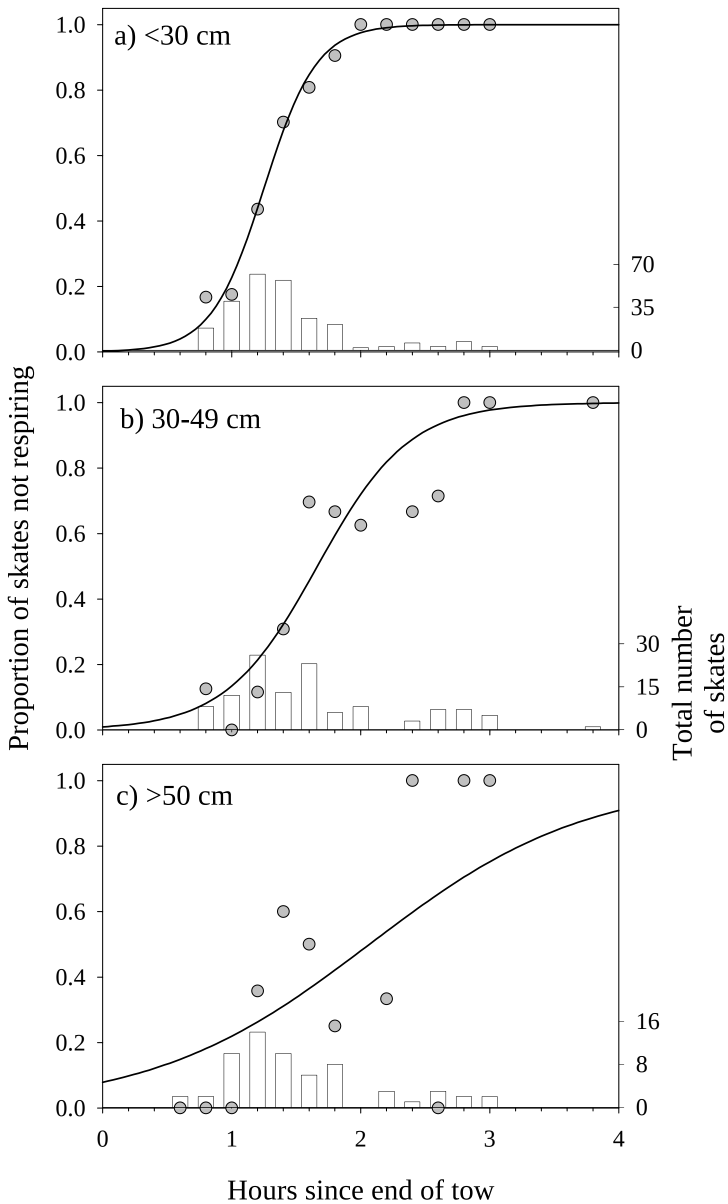

Figure 15. Observed and predicted proportion of skates not respiring (left axis), along with the frequency distribution of observations (right axis), as a function of the time elapsed since the end of the tow, for skates (a) <30 cm, (b) 30-49 cm and (c) >50 cm in length. The plotted observed values represent the average proportion in 0.2 hour intervals.

Appendix I. Median annual bycatch (kg, with 90% confidence interval) of winter skate in the southern Gulf of St. Lawrence, assuming no change in catch rates resulting from differences in the relative abundance of skates and commercially important species during 1971-1990. Estimates for 1999 are presented with (a) and without (b) the influential cod fixed-gear set.

year	*Observed winter skate*	*Observed winter skate + proportion (unident. skates)*	*Predicted winter skates*
1971	87,342 (50,947 / 133,661)	252,236 (161,070 / 417,431)	575,547 (395,178 / 841,819)
1972	81,889 (46,792 / 126,496)	239,844 (149,931 / 409,321)	539,600 (353,116 / 805,652)
1973	61,969 (36,076 / 95,382)	172,940 (113,074 / 280,229)	392,976 (277,621 / 564,306)
1974	63,405 (37,153 / 98,349)	182,356 (116,519 / 298,846)	421,628 (292,909 / 610,636)
1975	65,915 (38,197 / 101,927)	186,808 (119,853 / 303,204)	425,844 (295,847 / 616,397)
1976	59,126 (33,838 / 91,966)	155,111 (105,987 / 231,827)	371,093 (281,187 / 494,892)
1977	55,174 (30,672 / 88,586)	143,390 (92,842 / 225,447)	325,573 (234,042 / 454,612)
1978	70,198 (35,344 / 122,209)	176,014 (107,594 / 285,504)	371,239 (254,265 / 536,003)
1979	130,232 (57,394 / 248,642)	315,349 (179,334 / 528,297)	602,634 (393,657 / 897,420)
1980	106,585 (47,302 / 204,687)	258,724 (151,219 / 424,647)	503,593 (341,488 / 736,001)
1981	106,334 (54,537 / 180,405)	286,853 (172,760 / 483,252)	598,846 (387,069 / 901,098)
1982	93,113 (48,175 / 156,518)	258,611 (157,849 / 435,479)	552,807 (362,196 / 829,973)
1983	85,643 (47,096 / 135,460)	258,414 (155,535 / 452,009)	573,498 (362,307 / 875,049)
1984	93,342 (48,392 / 156,794)	238,461 (143,631 / 406,036)	493,530 (306,488 / 746,580)
1985	103,698 (55,957 / 167,873)	278,686 (170,837 / 471,950)	599,930 (387,535 / 899,862)
1986	134,032 (58,175 / 259,196)	324,431 (184,297 / 547,288)	629,621 (417,038 / 939,821)
1987	158,772 (57,495 / 338,652)	334,346 (180,811 / 563,264)	593,787 (399,271 / 875,199)
1988	134,714 (53,509 / 274,549)	307,216 (168,539 / 521,367)	559,227 (360,110 / 840,537)
1989	109,098 (49,858 / 202,828)	277,913 (161,656 / 468,982)	546,313 (353,646 / 822,539)
1990	86,203 (44,194 / 144,010)	240,672 (145,969 / 410,289)	512,727 (331,582 / 776,978)
1991	2,153 (360 / 4,186)	41,947 (23,130 / 63,795)	76,732 (54,428 / 101,956)
1992	10,118 (3,808 / 19,781)	66,714 (19,878 / 185,791)	148,510 (93,776 / 266,618)
1993	30,560 (7,772 / 73,883)	41,514 (17,370 / 84,143)	49,240 (31,065 / 74,840)
1994	3,543 (807 / 8,104)	27,396 (12,547 / 49,674)	31,705 (17,061 / 54,903)
1995	3,099 (833 / 6,432)	32,571 (22,351 / 43,745)	52,385 (38,397 / 67,833)
1996	10,207 (3,127 / 21,501)	27,493 (15,572 / 42,689)	31,306 (17,983 / 48,762)
1997	806 (179 / 1,556)	100,563 (63,691 / 138,001)	123,353 (84,553 / 160,649)
1998	121 (45 / 241)	145,44 (9,326 / 22,514)	31,787 (14,584 / 54,242)
1999a	0	425,305 (15,396 / 2,510,222)	434,815 (24,228 / 2,521,282)
1999b	0	26,047 (14,432 / 43,021)	34,011 (21,986 / 51,501)
2000	0	25,980 (7,812 / 54,876)	64,514 (40,286 / 98,213)
2001	1,684 (62 / 3,465)	30,128 (5,821 / 71,132)	49,719 (22,001 / 92,865)
2002	1,742 (51 / 4,230)	8,704 (2,748 / 19,957)	9,734 (4,269 / 20,852)
2003	5,313 (1,360 / 11,137)	6,761 (2,454 / 12,673)	6,532 (3,669 / 11,230)
2004	5 (1 / 16)	5,882 (2,409 / 9,628)	10,216 (7,914 / 13,338)

Appendix II. Median annual bycatch (kg, with 90% confidence interval) of winter skate in the southern Gulf of St. Lawrence, with a correction for changes in catch rates resulting from differences in the relative abundance of skates and commercially important species during 1971-1990. Estimates for 1999 are presented with (a) and without (b) the influential cod fixed-gear set.

year	Observed winter skate	Observed winter skate + proportion (unident. skates)	Predicted winter skates
1971	329,446 (165,882 / 649,379)	899,561 (505,716 / 1,644,064)	1,972,363 (1,180,029 / 3,331,519)
1972	287,080 (144,721 / 517,999)	819,410 (453,393 / 1,524,321)	1,801,113 (1,047,177 / 3,141,154)
1973	211,746 (106,359 / 394,501)	576,598 (330,494 / 1,057,771)	1,250,262 (744,755 / 2,123,593)
1974	214,177 (107,928 / 384,160)	602,588 (339,234 / 1,102,531)	1,322,729 (780,191 / 2,288,908)
1975	243,268 (109,957 / 500,173)	634,392 (343,080 / 1,199,247)	1,303,186 (759,031 / 2,261,199)
1976	184,434 (91,332 / 341,819)	465,083 (267,315 / 804,090)	1,035,197 (636,785 / 1,680,050)
1977	240,466 (83,685 / 612,337)	511,307 (251,252 / 969,524)	928,214 (529,021 / 1,556,039)
1978	402,009 (90,083 / 124,5281)	686,926 (282,041 / 1,607,462)	1,004,358 (564,014 / 1,705,536)
1979	976,458 (137,809 / 3558,124)	137,4555 (423,048 / 4,090,493)	1,473,524 (826,486 / 2,489,311)
1980	774,012 (98,786 / 3110,393)	103,8683 (298,718 / 3,485,953)	1,036,677 (630,144 / 1,701,631)
1981	407,417 (87,930 / 1780,544)	674,898 (267,756 / 2,156,927)	949,403 (578,110 / 1,560,076)
1982	327,671 (65,650 / 1303,320)	513,332 (204,059 / 1,593,929)	712,186 (449,819 / 1,149,049)
1983	132,091 (51,824 / 364,447)	295,735 (159,659 / 613,329)	568,378 (357,660 / 901,524)
1984	190,743 (46,764 / 653,233)	296,636 (130,488 / 820,117)	438,665 (282,102 / 667,903)
1985	156,761 (49,859 / 450,853)	284,712 (144,262 / 637,306)	510,545 (335,410 / 766,491)
1986	253,468 (52,118 / 845,360)	376,538 (150,816 / 1,012,430)	552,595 (366,292 / 841,905)
1987	258,021 (50,379 / 789,182)	377,936 (140,775 / 949,201)	512,308 (342,755 / 765,261)
1988	160,282 (41,405 / 470,576)	272,315 (122,999 / 597,736)	418,799 (279,009 / 629,805)
1989	102,415 (38,231 / 303,669)	223,458 (121,221 / 452,579)	409,058 (277,508 / 611,941)
1990	70,919 (34,802 / 146,219)	190,569 (114,587 / 318,119)	394,372 (263,435 / 591,615)
1991	2,153 (360 / 4,186)	41,947 (23,130 / 63,795)	76,732 (54,428 / 101,956)
1992	10,118 (3,808 / 19,781)	66,714 (19,878 / 185,791)	148,510 (93,776 / 266,618)
1993	30,560 (7,772 / 73,883)	41,514 (17,370 / 84,143)	49,240 (31,065 / 74,840)
1994	3,543 (807 / 8,104)	27,396 (12,547 / 49,674)	31,705 (17,061 / 54,903)
1995	3,099 (833 / 6,432)	32,571 (22,351 / 43,745)	52,385 (38,397 / 67,833)
1996	10,207 (3,127 / 21,501)	27,493 (15,572 / 42,689)	31,306 (17,983 / 48,762)
1997	806 (179 / 1,556)	100,563 (63,691 / 138,001)	123,353 (84,553 / 160,649)
1998	121 (45 / 241)	14,544 (9,326 / 22,514)	31,787 (14,584 / 54,242)
1999a	0	425,305 (15,396 / 2,510,222)	434,815 (24,228 / 2,521,282)
1999b	0	26,047 (14,432 / 43,021)	34,011 (21,986 / 51,501)
2000	0	25,980 (7,812 / 54,876)	64,514 (40,286 / 98,213)
2001	1,684 (62 / 3,465)	30,128 (5,821 / 71,132)	49,719 (22,001 / 92,865)
2002	1,742 (51 / 4,230)	8,704 (2,748 / 19,957)	9,734 (4,269 / 20,852)
2003	5,313 (1,360 / 11,137)	6,761 (2,454 / 12,673)	6,532 (3,669 / 11,230)
2004	5 (1 / 16)	5,882 (2,409 / 9,628)	10,216 (7,914 / 13,338)