Variation in indices of tag reporting rate in the British Columbia Sablefish (*Anoplopoma fimbria*) fishery

by

Brendan Aulthouse

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Declaration of Committee

Name:	**Brendan Aulthouse**
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Committee:	**Chair:** Olivia Gemmell, Master of Resource Management Candidate **Sean Cox** Co-Supervisor Professor, Resource and Environmental Management **Luke Rogers** Co-supervisor Research Scientist Fisheries and Oceans Canada

Abstract

Mathematical models in fisheries research that utilize tag return data require an estimate of the proportion of commercially caught tags that are returned (i.e., the tag reporting rate). In this study, I estimated an index of tag reporting rate in the British Columbia Sablefish fishery by comparing the prevalence of tags in the commercial fishery catch to the tag prevalence of a fishery-independent survey. I determined the effect of region, year, gear type, and size by fitting generalized linear models to the estimates of this index. The tag reporting rate index varied across size classes and gear types, with high indices of tag reporting rate for fish larger than the commercial size limit, and in the trap fishery. I concluded that factors such as gear selectivity and handling of catch are likely impacting the indices of tag reporting rate. Future studies could investigate the drivers of variation in the index of tag reporting rate and seek to identify sources of bias. Potential clustering of tagged fish should also be investigated.

Keywords: mark recapture; tag reporting rate; Sablefish

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1. Introduction

Tag return data from mark recapture studies allows researchers to estimate biological parameters such as movement rates, mortality, and abundance. When tags are recaptured by people other than researchers (e.g., volunteers, harvesters), it is important to understand the proportion of recaptured tags that are reported, as this has a scaling effect on the outputs of models that use tag return data.

Mark recapture research in fisheries relies on harvesters capturing and reporting tagged fish to researchers; however, some unknown proportion of tagged fish will typically go unreported, either deliberately, or due to observation error (i.e., failing to detect tagged fish). It is important to accurately estimate the proportion of captured tags that are reported (i.e., the tag reporting rate) to minimize bias in inferences drawn from tag return data. For example, movement and mark-recapture models require estimates of tag reporting rate to estimate movement rates (e.g., Hanselman et al., 2014), and mortality (Pine et al., 2003). Such models involve estimating expected tag returns, which is linearly dependent on the tag reporting rate; that is, any positive (or negative) bias in the tag reporting rate will directly cause an under-estimation (or over-estimation) of abundance. Abundance can be estimated using the Petersen method (Seber, 1982, p. 59), which can be adapted to incorporate a tag reporting rate via (Equation 1):

$$A = \frac{C \times T \times W}{N} \tag{1}$$

where A is the estimated population abundance (i.e., number of individuals), C is the catch (also number of individuals), T is the number of tagged fish in the population, N is the count of tag returns in the catch, and W is the estimate of tag reporting rate. The linear relationship between estimated abundance (A) and reporting rate (W) demonstrates that inaccurate estimates of reporting rate will lead to inaccurate estimates of abundance.

Methods for estimating tag reporting rate can be broadly classified into two categories (Hearn et al., 2003; Pollock et al., 2001; Pollock, Hoenig et al., 2002). It is possible to directly estimate tag reporting rate by secretly planting a known number of tagged fish in commercial catch and observing the proportion of these tags that are reported (e.g., Hearn et al., 2003; Hillary et al., 2008). This approach is limited by the need for secrecy, which can lead to small sample sizes (e.g., Hillary et al., 2008). In this study, I will focus on a second approach that compares tag prevalence in fishery catches to tag prevalence in a broad scale sampling platform, such as a fishery-independent survey that has a known reporting rate. This approach relies on three main assumptions: (1) the survey reports 100% of tagged fish caught; (2) the age composition is consistent between the survey and the commercial fishery; and (3) tagged fish are randomly mixed with untagged fish throughout the survey and fishery areas (Heifetz and Maloney, 2001). Survey reporting rate can be independently estimated via auxiliary studies (e.g., planting tags (Carruthers et al., 2014)), but it is often assumed to be 100% (e.g., Carruthers and McAllister, 2010; Heifetz and Maloney, 2001). Similarity of age or size composition can be verified by comparing the observed catch composition of fisheries with the observed catch composition of surveys (e.g., Heifetz and Maloney, 2001). The assumption of consistent size composition among fleets can be relaxed if reporting rate is estimated for discrete size classes (e.g., Carruthers et al., 2014), although this can be difficult to achieve due to the limited information about size composition in commercial catch. Variation in size composition of the catch between fleets could result in variable reporting rates if size data are not included in estimating reporting rates. Complete mixing of tagged fish within the vulnerable population is likely the most violated assumption in estimating tag reporting rates, especially when studies use repeated measures survey designs in which the same locations are visited each year (e.g., Haist et al., 2001; Heifetz and Maloney, 2001). In the case of repeated measures survey designs, the survey may be more likely to recover tagged fish than commercial fisheries, depending on the degree to which fish move after being tagged. Non-random mixing of tags within the population may result in non-random spatial effects in estimated reporting rate. The assumption of homogenous tag distribution can be relaxed by disaggregating catch and tag returns in space and time (Carruthers and McAllister, 2010). Due to the difficulty in satisfying these assumptions, this method is best thought of as estimating an index of tag reporting rate, rather than directly estimating a tag reporting rate.

Previous research on tag reporting rate indices has focused on estimating reporting rate indices for use in assessments (e.g., Heifetz et al., 2002; Hillary et al., 2008), or advancing the methods used to estimate reporting rates (e.g., Carruthers McAllister, 2010; Hearn et al., 1999). Little research has focused on identifying the sources of variation in tag reporting rate indices. Understanding which factors result in low indices of tag reporting rate could allow managers to focus efforts to increase tag reporting. Additionally, understanding sources of variation in tag reporting rate indices represents a first step in identifying potential sources of bias in tag return data.

In this study, I estimate an index of tag reporting rates for British Columbia Sablefish by comparing tag prevalence in longline trap, longline hook, and bottom trawl fishing fleets to tag prevalence in a stratified random trap survey. I use generalized linear models to determine how this index varies across areas, years, fleets, and size classes (above or below the commercial size limit (55 cm)). Understanding tag reporting rates for British Columbia Sablefish is important for improving model estimates of biological parameters (e.g., movement, mortality) and for stock assessment.

British Columbia Sablefish (*Anoplopoma fimbria*) have been tagged through various programs since 1977 (Haist et al. 2001). Prior to 1991, Sablefish tagging did not follow a consistent sampling design (Murie et al. 1995), whereas after 1991, tags were released as part of the fall Sablefish survey using consistent release and recovery locations (Haist et al. 2001). Attempts to estimate tag reporting rate as part of this program were deemed problematic due to consistent release localities (Haist et al, 2004). British Columbia Sablefish have been tagged as part of a stratified random survey since 2003. During the fall each year, Sablefish are sampled at random within five spatial and three depth strata (150-250 fathoms, 250-450 fathoms, 450-750 fathoms) (Wyeth et al., 2007). The stratified random survey benefits from following a robust scientific sampling design and can be assumed to randomly seed tagged Sablefish throughout the vulnerable population. Given that commercial fisheries operate throughout the same area as the survey, this represents a unique opportunity to compare commercial and survey fleets that can reasonably be assumed to target the same fish.

The stratified random survey design best satisfies the assumptions required to estimate the index of tag reporting rates. It can be assumed that the survey reporting rate is 100% across all survey designs. Survey reporting rates should only deviate from 100% due to observation errors, and there is no reason to expect different levels of observation error between survey types. The second assumption requiring consistent age composition between commercial and survey fleets is unlikely to be satisfied under any survey design, due to differences in selectivity and catchability of gear types. For example, commercial traps feature escape rings to avoid juvenile Sablefish, while the survey traps do not (Haist et al., 2004). Differences in size composition of catch between fleets can partly be accounted for by incorporating size data in the estimation of reporting rate indices. The benefit of the stratified random survey is that it theoretically best satisfies the third assumption of mixing tagged fish throughout the vulnerable offshore population. It cannot be assumed that previous survey designs such as the standardized survey (Haist et al., 2001) randomly mixed tagged fish in the vulnerable offshore population due to the repeated measures designs used. Tags released and recovered through the stratified random survey are therefore likely to give an index of reporting rate closest to a direct estimate of tag reporting rate.

2. Methods

I estimated indices of tag reporting rate for Sablefish across three commercial fisheries by comparing commercial tag prevalence to survey tag prevalence, for each combination of survey area, year, gear type, and size. I then fit generalized linear models of the reporting rate indices using an all subsets approach, to estimate sources of variation in the index. I determined goodness of model fit by using the small sample approximation of Akaike's Information Criterion (Hurvich and Tsai, 1989).

2.1 Data

All data was provided by Fisheries and Oceans Canada (Lisa Lacko, *personal communication,* October 12, 2019). Tag release and recovery data were extracted from the Pacific Regional database FishTag. Commercial catch data was obtained from the Groundfish Fishery Operations System (GFFOS), PacHarvTrawl, PacHarvSable, and PacHarvHL databases. Survey catch data was obtained from the Groundfish Science Biological database (GFBIO). Catch and tag returns from the survey and fisheries were stratified by year (2003-2017), stratified random survey area (S1-S5) (Figure 1), gear type (trap, longline, trawl, and stratified random survey trap), and size class (sublegal (<55 cm), legal (≥55 cm).

Between 2003 and 2017, the stratified random survey released 106 262 tags at random locations within the 5 stratified random survey spatial strata (Figure 1). This survey region overlaps to a large degree with commercial trap and longline fisheries, and moderately overlaps with trawl (Figure 1).

Over the same period, a combined total of 9 847 stratified random survey tags have been recovered in the trap fishery (6 517 tags), the longline fishery (2 408 tags), the trawl fishery (457 tags), and the survey (465 tags).

All tag recoveries were directly observed, either by researchers conducting the survey, harvesters or at-sea observers for commercial fleets. Total catch (pieces) was observed directly in the survey. Some catch and tag returns did not have a size recorded at the time of recovery and therefore could not be attributed to either sublegal or legal size classes. The proportion of tag returns not attributed to a size class is similar across commercial fleets and the stratified random survey (Figure 2). Catch from the stratified random survey that is not attributed to either the legal or sublegal size classes occurs because one-third of traps in each stratified random survey string are discarded without being measured for length or weight (Haist et al. 2005). Approximately 52% of the survey total catch did not have observed size data; as such, the unsized proportion of catch was attributed to size classes based on the yearly proportion of catch that was sized. Commercial catch (pieces) was estimated from catch weight, by assuming an average 3.0 kg per retained adult fish, and 1.5 kg for released fish, which were assumed to be less than the 55 cm size limit (e.g., Cox et al 2011).

I included tag recoveries from 2006 up to, but not including 2018 (Table 1, Table 2). The number of survey tag returns before 2006 and after 2017 were not sufficient to estimate tag prevalence ratios. I did not use a requirement for minimum time at liberty, as the stratified random survey design should satisfy the need for mixing of tagged fish in the population. I limited tag recoveries to the stratified random survey areas, to ensure commercial and survey fishing effort overlapped. All commercial recoveries and catch outside of the five stratified random survey areas were excluded because commercial data from outside of the five stratified random survey areas would likely underestimate reporting rate, as tagged fish are not released in these areas and are thus less likely to be recovered.

2.2 Estimating Tag-Reporting Rates

The stratified random survey for Sablefish was used as a baseline for prevalence of tags in the catch to estimate an index of tag reporting rates by area, year, gear type, and size. The ratio of commercial fishery tag prevalence to survey tag prevalence is given by (Heifetz and Maloney, 2001)

$$W_{a,y,g,s} = \frac{N_{a,y,g,s} m_{a,y,s}}{M_{a,y,g,s} n_{a,y,s}} \quad \text{(2)}$$

where $W_{a,y,g,s}$ represents the estimated ratio of commercial and survey tag prevalence for survey area a, year y, gear type g, and size class s, $n_{a,y,s}$ is survey tag recoveries, $m_{a,y,s}$ (in pieces) is the survey total catch, $M_{a,y,g,s}$ (in pieces) is commercial fishery catch, and $N_{a,y,g,s}$ is reported tag recoveries from the commercial fishery. $W_{a,y,g,s}$ represents an estimated index of tag reporting rate for data pooled over one year for each area, gear type, and size class. I estimated the variance (Appendix) of the index of tag reporting rate by using the delta method and assuming binomial variance in the survey and commercial tag prevalence (e.g., Wolter, 2007). I assumed no covariance between survey and commercial tag prevalence.

2.3 Models for reporting rate

I modelled effects of survey area, year, gear type, and size on the index of tag reporting rate via the following (full) logit-link generalized linear model with binomial error structure:

$$logit(W_{a,y,g,s}) = \beta_0 + \beta_{1,a}a + \beta_{2,y}y + \beta_{3,g}g + \beta_{4,s}s + \beta_{5,a,g}a * g + \beta_{6,a,s}a * s + \beta_{7,s,g}s * g \tag{3}$$

where β_x indicates the coefficients for each variable. Variable levels are as follows: $a \in$ {S1, S2, ..., S5}, $y \in$ {2006, ..., 2017}, $g \in$ {trap, longline, trawl}, and $s \in$ {sublegal and legal}. After fitting the full generalized linear model (Equation 3), I fit all subset models to identify which combination of variables best fit the index of tag reporting rate.

The logit link has been used in other studies to model direct estimates of reporting rates (e.g., Berger et al., 2014). I estimated an index of tag reporting rates by comparing tag prevalence, which means estimates were not necessarily less than 1. In order to use the logit link, I constrained the estimated reporting rates to (0,1), by assigning a value of 1 to any finite estimates over 1 (i.e., commercial catch had higher prevalence of tags than survey catch). Estimated reporting rate indices may be greater than 1 due to my approximation to the actual catch in pieces or due to uncertainty introduced from low survey sample size. Specifically, much lower survey catch compared to the commercial fleets means that the survey also returns far fewer tags

(Table 1, Table 2). Under these low tag sample sizes, observed values are more likely to deviate from expected values.

I treated all covariates in all models as categorical variables to identify particular years that had high or low reporting rates rather than trying to identify an increasing or decreasing trend throughout the time-series. I hypothesized that changes to reward program, as well as requirements to relinquish whole tagged fish before 2017 (Canadian Sablefish Association, 2019) would result in single year effects on reporting rate index, rather than a linear trend.

2.4 Evaluating Model Fit

I ranked models via the Akaike Information Criterion for small sample sizes (AICc) (Hurvich and Tsai, 1989) (Equation 4):

$$AICc = 2p - 2\ln(\hat{L}) + \frac{2p(p+1)}{(o-p-1)} \tag{4}$$

where $\hat{L}$ is the maximum likelihood function value, *p* is the number of model parameters, and *o* is the number of observations. I used the small sample size corrected AICc based on the recommendation in Burnham and Anderson (2002) (i.e., $\frac{o}{p} < 40$) given my sample size of *o* = 273. I identified significant variables within top models using a Wald test (Wald, 1943).

3. Results

The mean tag reporting rate index across all years and areas for legal size Sablefish in specific fleets are as follows: 0.63 in the trap fleet, 0.24, in the longline fleet, and 0.20 in the trawl fleet (Figure 3). The mean sublegal tag prevalence ratios are 0.45 in the trap fleet, 0.10 in the longline fleet, and 0.08 in the trawl fleet (Figure 3).

Size was the most important factor driving variation in reporting rate indices for tagged Sablefish. All top models fit to estimates of tag reporting rate indices included size as a covariate (Table 3). Three models received AICc weights of greater than 0.05 when fit to the tag reporting rate indices, and all of these models included size class as a main effect. The top model by AICc weight included size class and gear type as main effects, with no interaction effects (Table 3). The top model received 0.81 of the AICc weight, with the next ranked models receiving 0.08. This corresponds to an evidence ratio (Burnham and Anderson, 2002) of 10.1, indicating strong support for the top model.

Gear type was also an important source of variation in tag reporting rate indices. Gear type was included as a main effect in the top three models, with the exception of the second ranked model, where it was included in an interaction term (Table 3). Year and stratified random survey area were not included in any of the top three models (Table 3).

In all of the top three models, the sublegal size class had significantly lower tag reporting rate index ($p < 0.05$) than the reference case (legal size class) (Table 4). The trap gear type had significantly higher tag reporting rate index ($p < 0.05$) than the reference case (longline) across all models that included gear type as a main effect and received AICc weight (Table 2). The trawl fishery was never significantly different from the reference case (longline). Interaction terms between size and gear type were included in two of the top models (Table 3), and some of these interactions were significant ($p < 0.05$) (Table 4). However, the interaction terms were only significant in the model that did not include gear as a main effect, and the interaction plot does not indicate any interactions between gear and size (Figure 4).

4. Discussion

In this paper, I asked how the ratio of commercial fishery tag prevalence to survey tag prevalence in the BC Sablefish fisheries varied across survey area, year, commercial gear type, and size class. I generated logit-link generalized linear models to determine effect size of these variables on the estimated index of tag reporting rate. Tag reporting rate indices varied mainly as a function of size class (legal or sublegal) and gear type. Stratified random survey area and year were not significant sources of variation in tag reporting rate indices.

The index of tag reporting rate in the BC Sablefish trap fishery was high compared to a similar study of Alaskan sablefish, where tag reporting rate indices of 0.17 - 0.38 were estimated (Heifetz and Maloney, 2001). The comparatively high reporting rate index may be due to harvesters better cooperating with the tagging program, because the rewards for reporting tagged fish in British Columbia (Canadian Sablefish Association, 2019) are higher value than they are in Alaska (NOAA, 2019). In addition to fisher compliance, the high indices of reporting rate in the Sablefish fishery, particularly in the trap fleet, may indicate a success of the stratified random survey. Using repeated measures survey designs (e.g., the Alaskan longline survey (Heifetz and Maloney, 2001)) can bias tag prevalence ratios by sampling fish in the same area that they were released. Repeatedly sampling the same locations may lead to clustering of tagged fish, which would result in higher variance due to non-independent tag returns. Furthermore, if tagged fish are clustered around survey stations, the survey will be more likely to encounter tagged fish than commercial fleets, and the reporting rate index will be negatively biased relative to the true tag reporting rate.

Lower reporting rate index in sublegal size class

Size class was the most significant variable in determining reporting rate index. This may be due to the behaviour of harvesters within the Sablefish fishery. Sublegal fish must be discarded when caught commercially, so they are likely handled much less than the legal sized fish, which are processed (DFO, 2019). The lower handling time of sublegal fish may lead to higher incidence of observation error in tag reporting. Failure to find tags was identified as the leading reason for nonreporting in a study of recreational anglers in Florida (Matlock, 1981). Observation error may also be high due to the low rate at which tagged, sublegal fish are encountered.

It is also possible that there is a lower index of tag reporting rate in the sublegal size class due to reasons other than tag reporting by harvesters. While tag returns and catch were limited to the stratified random survey region, this is not a closed system. Some portion of sublegal fish is thought to move from the inlets to the offshore areas as they mature (Mason et al., 1983). These incoming fish may come in contact with commercial fisheries, before they have an opportunity to be tagged in the survey. This influx of untagged sublegal fish could be negatively biasing the index of tag reporting rate, by increasing the catch of untagged Sablefish (M, equation 2). Sublegal fish may be more likely to encounter trawl and longline vessels, which typically fish in shallower water. This could partially explain why tag reporting rate indices are particularly low for sublegal fish in these fleets. This could be better accounted for by including tags from other sources. For example, sublegal fish are tagged in British Columbia inlets (Lacko et al., 2020), and Alaska (NOAA, 2019). Including these tag returns may reduce negative bias in the index of tag reporting rate, by better accounting for Sablefish movement.

Size based variation in reporting rate indices may also be due to differences in selectivity between survey and commercial gear. In previous research, differences in size (or age) structure of the catch between commercial fleets and the survey fleet have been shown to lead to unreliable estimates of reporting rate (Hearn et al., 1999). Commercial traps use escape rings, which increase the average size of catch by allowing small fish to escape, while survey traps have escape rings sewn shut (Haist et al., 2004). Selectivity functions indicate that the trap and longline fisheries have lower selectivity for small fish than the stratified random survey (Cox et al., 2019). This difference in selectivity could affect estimated reporting rate indices by increasing the average weight of sublegal catch from the assumed 1.5 kg (derived from survey catch). Higher average catch weight will inflate the estimated commercial catch (in pieces) ($M_{a,y,g,s}$), thus reducing the estimated ratio of commercial tag prevalence to survey tag prevalence ($W_{a,y,g,s}$)(Equation 2). Estimated indices of tag reporting rate are likely sensitive to small changes in catch, because of the low sample size of sublegal tag returns.

Low indices of tag reporting rates in the sublegal size class have implications for Sablefish management. Given the low index of tag reporting rate, commercial tag returns are not a rich source of data for sublegal Sablefish and should thus not be relied upon in assessments of sublegal fish. Fortunately, there are other programs already in place to study sublegal fish, such as the inlet survey (Wyeth et al., 2007). However, the offshore stratified random survey and the associated commercial tag returns may still be useful in understanding the offshore dynamics of sublegal Sablefish. Reporting of inlet program tags in commercial fisheries is highly relevant in assessing conservation issues such as bycatch and should be studied in the future.

Previous research on the effect of size on reporting rate has shown variable results. While I estimated higher indices of tag reporting rate in large size classes, previous research on reporting rates of Southern Bluefin Tuna has found reporting to be higher in small sizes (Pollock, Hearn et al., 2002). In many cases, size data is not used at all; studies of reporting rates indices in Atlantic Ocean tuna fleets (Carruthers and McAllister, 2010) and the Alaskan Sablefish fishery (Heifetz and Maloney, 2001) did not investigate size class effects because size and age data were not available. In future research, differences in size composition of catch could be controlled for by increasing the number of size classes. Unfortunately, it is difficult to estimate reporting rate for multiple size classes due to data limitations. Future studies could attempt to account for differences in size composition by including selectivity functions, or extrapolating from the subset of commercial catch that is sampled for size.

High tag reporting rate indices in the Sablefish trap fishery

The British Columbia Sablefish trap fishery has significantly higher tag reporting rate indices than both the trawl and longline fisheries. This difference may be due to operational differences in each fishery. All fleets use some form of observers or monitoring, so it is likely that factors beyond nonreporting are causing low indices of tag reporting rate in the trawl and longline fisheries. One such factor may be that the assumption of consistent size composition between fleets is not being met. There is variation in selectivity and distribution of fishing effort that was not accounted for in this analysis due to the relatively low resolution of the size and spatial data. Recovery probability of a tagged Sablefish has been shown to be dependent on the size of the fish at release, with larger fish more likely to be recovered (Saunders et al., 1990). The trawl fishery has low selectivity for large fish (Cox et al., 2019), which could reduce the estimated index of reporting rate. The longline fishery has similar selectivity to the survey and commercial trap, but typically operates in shallower water than the trap survey and fishery (Lisa Lacko, *personal communication*, October 19, 2020). By operating mainly in the shallowest depth strata of the stratified random survey, the longline fleet may be less likely to encounter tagged fish, thus reducing indices of tag reporting rate.

The differences in reporting rates indices between commercial fleets could also be due to behavioural differences among harvesters. The trap fleet is the dominant fishery for BC Sablefish, accounting for 67% of combined legal and sublegal catch between 2003 and 2018. Previous research has indicated that reporting rate indices are higher in target fisheries than in nontarget fisheries (Schmalz et al., 2004). The trap fleet has dedicated licenses and is supportive of Sablefish research (e.g., Cox et al., 2011), indicating an interest in the long-term viability of the stock. Thus, trap harvesters may be more aware of the benefits and rewards of reporting tagged fish. In addition, fisher behaviour such as the handling of catch is variable between fleets. Sablefish undergo more extensive processing on trap vessels than other fleets. This increase in handling and processing of fish may increase reporting rate indices by reducing the observation error of harvesters.

The difference in tag reporting rate indices between fleets is significant for the BC Sablefish fishery and has implications for tagging research more broadly. The fleet specific indices of tag reporting rate need to be accounted for in assessments that use tag return data, due to the scaling effect they can have on model outputs (e.g., Equation 1). If the indices of tag reporting rate are low due to nonreporting (e.g., because of observation error) then they can be applied to assessments and future research without issue. However, if the indices are low due to bias (e.g., due to differences in selectivity), then this bias will be reflected in assessments and future research. Future research is needed to identify the specific drivers of the fleet specific indices of reporting rate. The difference in tag prevalence ratio between fleets is also significant for tagging research generally. Researchers typically call for an increase in fishery observation when reporting rate indices are low (e.g., Carruthers et al., 2014). The British Columbia groundfish bottom trawl fleet uses at-sea observers while the trap and longline fleets use electronic monitoring. The low reporting rate in the trawl fleet indicates that at-sea observers may not be an effective way to improve tag reporting rates. Further research is needed to investigate the specific drivers of the difference in the index of tag reporting rate between fleets. For example, differences in the distribution of fishing effort could be better accounted for by increasing the resolution of spatial area, or by including fishing depth as a predictor. Differences in reporting rate due to observation error or nonreporting could theoretically be detected by planting tagged fish in commercial catch; however, this is not feasible in the Sablefish fishery due to the way that catch is handled (Haist et al., 2004). Interviewing harvesters may also help determine the source of variation in reporting rate indices between fleets (e.g., Matlock, 1981)

The estimated index of reporting rates does not vary significantly across either stratified random survey area or through time. This is important as it may demonstrate the robustness of the survey design. Given that fishing effort is unlikely to be random, it is important to sample and tag fish randomly in the survey. This is especially relevant with a species like Sablefish, where some portion of adult fish is thought to move very little (Beamish and McFarlane, 1988). Other studies have found spatial and temporal variation in reporting rate. For example, time was a significant variable in models fit to reporting rates of Indian Ocean tuna (Hillary et al., 2008). A study of reporting rate indices for Alaskan Sablefish did not use a modelling approach to determine the effect of variables such as area and year, estimates of reporting rate were highly variable (Heifetz and Maloney, 2001). For example, in 1992 indices ranged from 5% to 52% among areas. The reporting rate indices in British Columbia may be more stable across areas and years because of the stratified random survey mixing tags better than the Alaskan longline survey. This difference in surveys may also explain why the Alaska study generally had lower tag reporting rate indices. The consistent release and recovery locations in the Alaskan survey may inflate the proportion of tags in the survey catch, thus decreasing the estimated reporting rate indices.

Limitations

Estimates of tag reporting rate index were limited by the data that was available. To better understand the effect that size may have on the index of reporting rate, future studies would need the size data in much finer resolution. The relationship between size and the index of tag reporting rate is likely more complicated than I investigated in this study. For example, tag reporting rate index may vary across sizes within the legal size class because of selectivity or harvester behaviour, but I was not able to investigate this difference. This was not possible because not all fish are sized in the current survey, and it is not feasible to get complete size data from the commercial catch. Data limitations also affected the potential variables that could be investigated. Increasing the dimensionality of the dataset by estimating reporting rates across more variables (e.g., depth strata) would introduce uncertainty by limiting the sample size in each combination of variables. However, now that it seems that tag prevalence ratio does not vary across space and time, it may be possible to aggregate catch and tag returns to investigate other variables in future research.

I was also limited to catch and tag return data that were aggregated, and I did not have access to individual tag returns. This meant that I was not able to assess potential clustering and overdispersion of tag returns. Overdispersed tag return data requires more complex modelling methods to account for the increased variance, such as a negative binomial likelihood function (e.g., Carruthers et al., 2014). If the overdispersion was not accounted for, the uncertainty of estimated tag prevalence may have been underestimated. Underestimating the uncertainty of the tag reporting rate could lead to underestimating uncertainty in estimates of abundance (Equation 1), which could lead managers to not set precautionary harvest rates.

Some estimated indices of tag reporting rate are highly uncertain, particularly for sublegal fish, due to the low number of sublegal catch and tag returns in both the survey and commercial fleets. As such, the indices of tag reporting rates for sublegal Sablefish should be treated with some skepticism. It may be possible to reduce this uncertainty by including tags from other surveys (e.g., Alaska) in future studies, in order to increase the number of sublegal tag returns.

I assumed all discards were sublegal (i.e., < 55cm), and that all landed catch was legal. This ignores the possibility that commercial harvesters may be retaining sublegal fish or discarding low-value legal fish. This assumption was necessary as it was the only way to include size data in this analysis. Given the at-sea and electronic monitoring in the commercial Sablefish fleets, the degree of misclassified size classes may be minimal. Further, given the magnitude of the size effect, it is unlikely that some error due to the grading of fish is the cause of the significant difference in tag reporting rate indices between size classes. I also assumed that any estimated indices of reporting rate greater than 1.0 were equal to 1.0. This was necessary in order to fit the binomial GLMs.

Reporting rates greater than 1.0 reflect uncertainty in the survey due to low tag returns, and only affected the trap fishery. Other studies have used prior distributions to constrain estimates between 0 and 1 (e.g., Carruthers et al., 2014), which likely would have a similar effect.

Conclusions

In this study, I demonstrated that indices of tag reporting rate in British Columbia Sablefish fisheries are most influenced by size and gear type. Indices of tag reporting rate were highest in the legal size class, and in the trap fishery. This is significant for managing tagging programs, as it demonstrates that indices of tag reporting rate are influenced by factors other than the level of observation. For example, differences in size composition of catch, caused by selectivity and distribution of fishing effort, could bias the index relative to the true tag reporting rate. Alternatively, differences in handling behaviour of harvesters between fleets, or between size classes within fleets, may lead to different rates of observation error. The indices of tag reporting rate estimated in this study can be used in future Sablefish research and assessments to estimate biological parameters such as abundance and movement rates. Future research could investigate the drivers of differences in tag reporting rate indices across gear and size classes, by better accounting for the differences in size composition between fleets. This could be done by increasing the resolution of size data, incorporating selectivity functions into the analysis, or by accounting for effort distribution by including depth data in the analysis. Understanding the drivers of these differences is important to identify if indices of tag reporting rate may be biased relative to the true tag reporting rate. Potential clustering of tagged fish should also be investigated, because of the implications it can have on estimates of uncertainty.

5. Tables

Table 1. Commercial catch and tag returns used to estimate commercial tag prevalence for the tag reporting rate index. Gear refers to one of the three commercial Sablefish fleets, Year refers to the year in which fish were caught, Legal catch (in pieces) is the estimated count of Sablefish larger than 55 cm (fork length), Sublegal catch (in pieces) is the estimated count of Sableifsh less than 55 cm, Legal Tags is the count of tagged Sablefish larger than 55 cm that were reported, and Sublegal Tags is the count of tagged Sablefish smaller than 55 cm that were reported.

Gear	Year	Legal Catch	Sublegal Catch	Legal Tags	Sublegal Tags
Longline	2006	377475	179539	130	5
Longline	2007	333646	86599	102	7
Longline	2008	381674	71914	153	4
Longline	2009	344678	68063	144	6
Longline	2010	414111	94390	158	3
Longline	2011	344017	93009	165	8
Longline	2012	398435	116579	204	21
Longline	2013	278940	86380	159	7
Longline	2014	312710	51241	164	5
Longline	2015	412679	82548	149	10
Longline	2016	322762	51971	169	9
Longline	2017	298519	60735	123	8
Trap	2006	787242	122967	479	22
Trap	2007	666238	100767	597	31
Trap	2008	482957	91785	514	31
Trap	2009	381676	54359	364	18
Trap	2010	252437	62138	454	17
Trap	2011	256378	74953	239	34
Trap	2012	241676	84526	379	44
Trap	2013	278343	111139	404	50
Trap	2014	188811	68334	263	36
Trap	2015	369213	76686	495	65
Trap	2016	232285	66260	310	34
Trap	2017	227569	88296	300	61
Trawl	2006	112695	61918	11	2
Trawl	2007	67662	64526	17	3
Trawl	2008	97294	28088	24	15
Trawl	2009	66571	25057	28	4
Trawl	2010	63172	52673	30	10
Trawl	2011	53042	65378	17	8
Trawl	2012	48181	78221	24	7
Trawl	2013	55008	75485	30	6
Trawl	2014	42517	74941	19	8
Trawl	2015	41571	119714	19	10
Trawl	2016	33599	147351	20	10
Trawl	2017	27394	212706	13	0

Table 2. Survey catch and tag returns used to estimate survey tag prevalence for the tag reporting rate index. Gear refers to only the stratified random survey, Year refers to the year in which fish were caught, Legal catch (in pieces) is the estimated count of Sablefish larger than 55 cm (fork length), Sublegal catch (in pieces) is the estimated count of Sableifsh less than 55 cm, Legal Tags is the count of tagged Sablefish larger than 55 cm that were reported, and Sublegal Tags is the count of tagged Sablefish smaller than 55 cm that were reported.

Gear	Year	Legal Catch	Sublegal Catch	Legal Tags	Sublegal Tags
StRS	2006	20466.3511	3638.64888	15	2
StRS	2007	16109.5668	2723.43316	31	5
StRS	2008	18191.1218	2090.87817	20	0
StRS	2009	13549.6242	1982.37578	19	2
StRS	2010	13678.4415	3696.55852	36	5
StRS	2011	15528.0528	7052.94722	27	4
StRS	2012	12443.2844	4402.71564	31	3
StRS	2013	14731.6249	4087.37513	32	8
StRS	2014	10097.0589	4207.94105	28	7
StRS	2015	18195.2653	7232.73473	52	17
StRS	2016	12747.3222	5331.6778	32	11
StRS	2017	20454.9623	16149.0377	44	9

Table 3. Model selection evidence for the generalized linear models of tag reporting rate index. The model column indicates which parameters were included in the generlized linear model (e.g., Equation 3), K is the count of parameters, Residual DoF is the residual degrees of freedom, ΔAIC_c is the difference in AIC_c values from the top model and the other models examined, AICc Wt. is the model weight, and NLL is the negative log-likelihood.

Model	K	Residual DoF	AICc	ΔAIC_c	AICc Wt.	NLL
Gear + Size	4	269	234.72	0.00	0.81	113.3
Size + Gear:Size	6	267	239.42	4.70	0.08	113.5
Gear + Size + Gear:Size	6	267	239.42	4.70	0.08	113.5

Table 4. Coefficient estimates (in logit space) for the top models fit to estimates of reporting rate index chosen by AICc.

Model	Parameter	Estimate	Std. Error	z	P. Value
Gear + Size	Intercept	-0.8266	0.2630	-3.143	< 0.001
	Gear- Trap	1.8350	0.3527	5.203	< 0.001
	Gear- Trawl	-0.3241	0.3793	-0.855	0.392
	Size- Sublegal	-1.5210	0.3501	-4.344	< 0.001
Size + Gear:Size	Intercept	-0.8009	0.2792	-2.869	< 0.01
	Size- Sublegal	-1.6875	0.7305	-2.310	< 0.05
	Size Legal : Gear- Trap	1.7453	0.4008	4.355	< 0.001
	Size Sublegal : Gear- Trap	2.0798	0.7682	2.707	< 0.01
	Size Legal : Gear- Trawl	-0.3104	0.4091	-0.759	0.450
	Size Sublegal : Gear-Trawl	-0.4434	1.0616	-0.418	0.676
Size + Gear + Size:Gear	Intercept	-0.8009	0.2792	-2.869	< 0.01
	Gear- Trap	1.7453	0.4008	4.355	< 0.001
	Gear- Trawl	-0.3104	0.4091	-0.759	0.448
	Size- Sublegal	-1.6875	0.7305	-2.310	< 0.05
	Gear- Trap: Size: Sublegal	0.3345	0.8664	0.386	0.699
	Gear-Trawl: Size- Sublegal	-0.1329	1.1377	-0.117	0.907

6. Figures

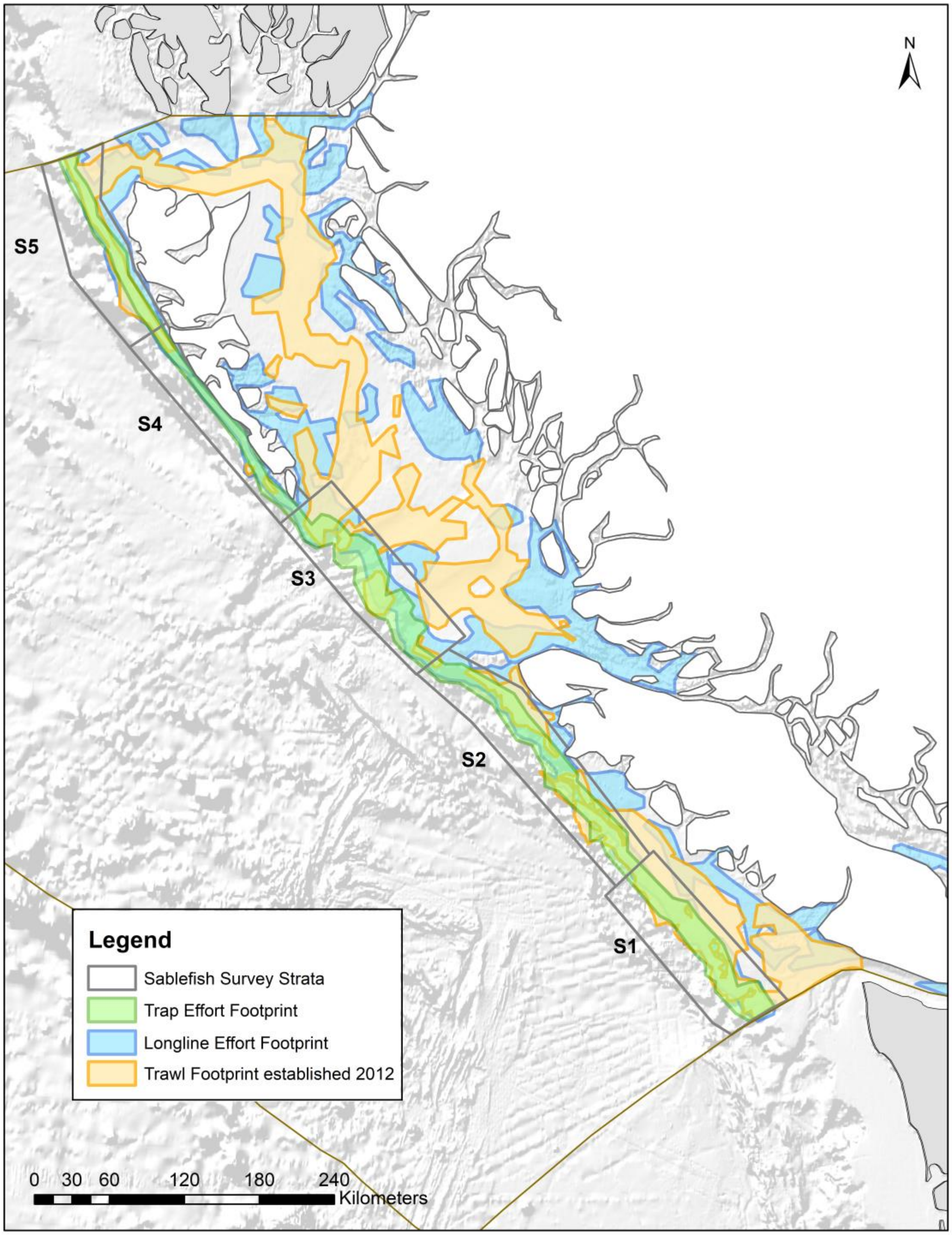

Figure 1. **Spatial extent of fishing effort for the three commercial fisheries (from 2011-2020), and the 5 stratified random survey spatial strata (Lisa Lacko, *personal communication,* December 18, 2020).**

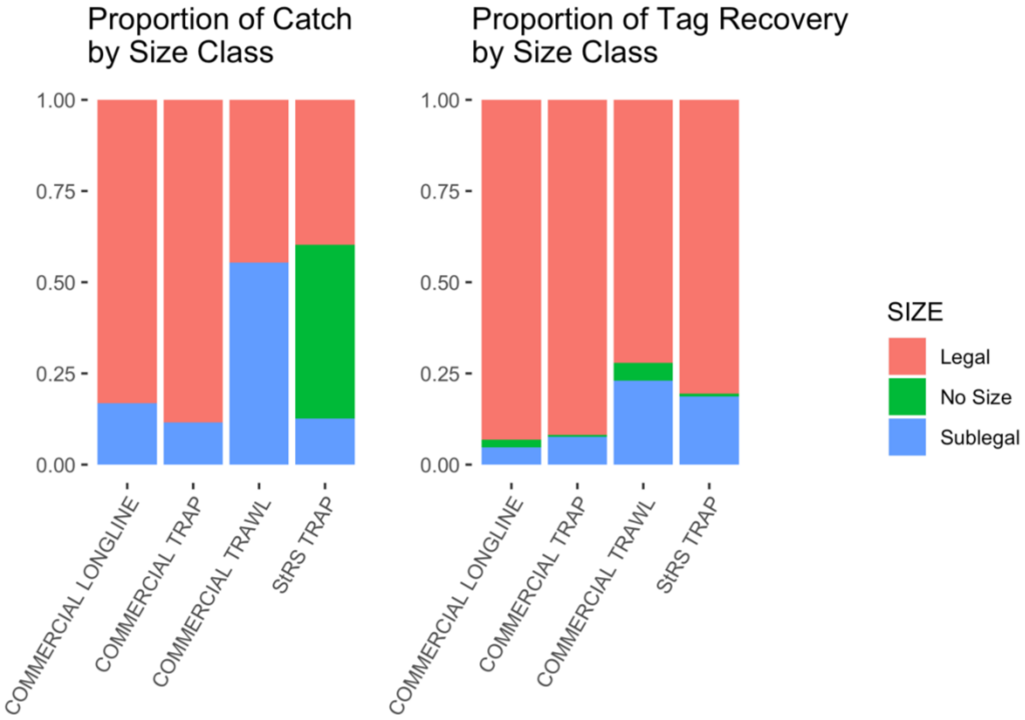

Figure 2. Size composition of the total catch (left) and tag recoveries (right) for all recapture fleets. StRS refers to the Sablefish stratifed random survey.

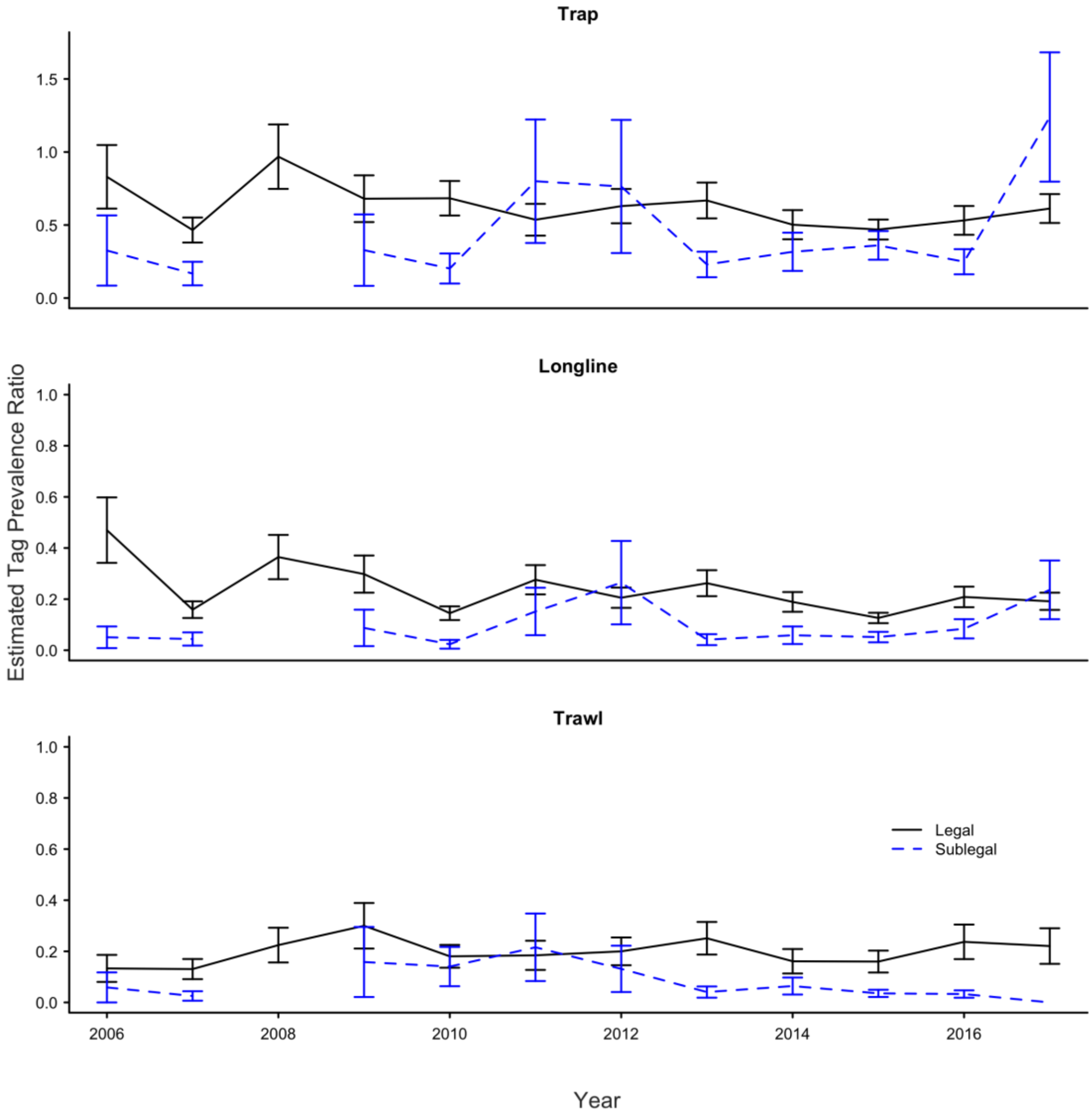

Figure 3. **Estimated tag prevalence ratio (W, Equation 2) for legal and sublegal fish in the three fisheries, across all areas. Error bars represent +/- 1 standard error.**

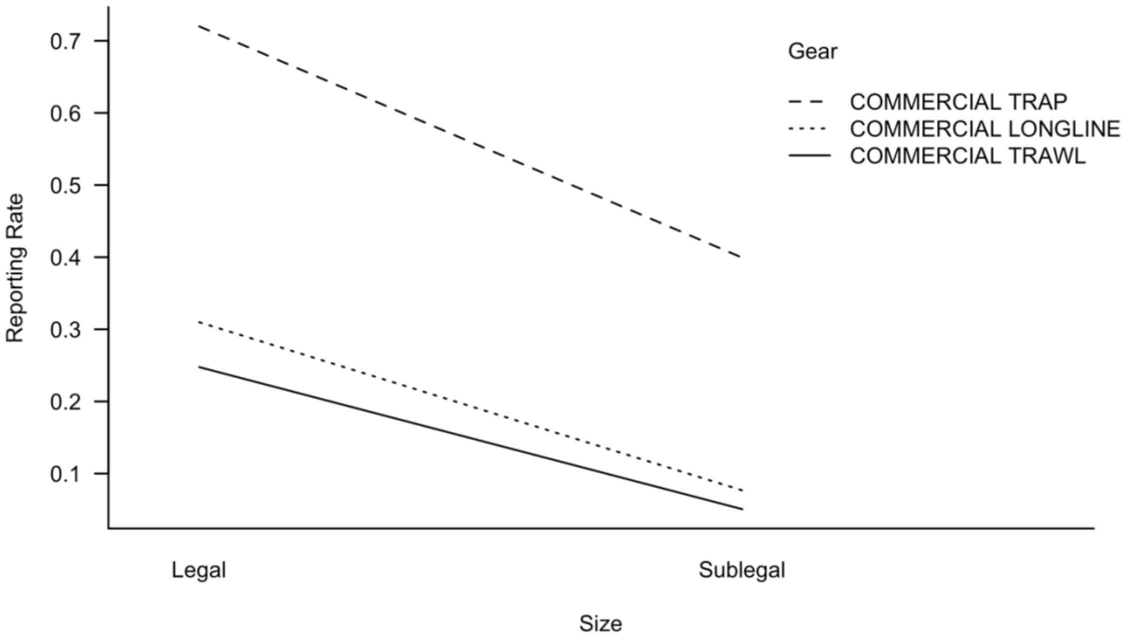

Figure 4. **Interaction between size and gear type on the estimated reporting rate index (W, Equation 2).**

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Appendix. Estimation of index of tag reporting rate

I estimated the variance of the index of tag reporting rate (W) by using the delta method and assuming binomial variance in the survey and commercial tag prevalence (e.g., Wolter, 2007, p. 240).

I estimated the variance of the commercial tag prevalence $F_{a,y,g,s}$ by assuming a binomial variance of a proportion (dropping subscripts for simplicity).

(A.1)

$$F_{a,y,g,s} = \frac{N_{a,y,g,s}}{M_{a,y,g,s}}$$

(A.2)

$$Var(F) = \frac{F \times (1 - F)}{M}$$

where F is the commercial tag prevalence, N is the count of commercial tag returns, M is the estimated commercial catch (in pieces), and $Var(F)$ is the estimated variance of the commercial tag prevalence.

I estimated the variance of the survey tag prevalence $S_{a,y,s}$ in the same way:

(A.3)

$$S_{a,y,s} = \frac{n_{a,y,s}}{m_{a,y,s}}$$

(A.4)

$$Var(S) = \frac{S \times (1 - S)}{m}$$

where S is the survey tag prevalence, n is the count of survey tag returns, m is the survey catch (in pieces), and $Var(S)$ is the estimated variance of the survey tag prevalence.

I then used the delta method (e.g., Wolter, 2007) to determine the variance of the ratio (Equation A.5), assuming no covariance between S and F. I then converted the variance of the estimate to standard error (Equation A.6):

(A.5)

$$Var(W) = W^2 \times \left(\frac{Var(F)}{F^2} + \frac{Var(S)}{S^2}\right)$$

(A.6)

$$SE(W) = \sqrt{Var(W)}$$

where W is the estimated index of tag reporting rate, $Var(W)$ is its variance, and $SE(W)$ is its standard error.