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DEVELOPMENT AND EVALUATION OF A METHODOLOGICAL APPROACH FOR ESTIMATING THE POST-CAPTURE SURVIVAL OF TRAWL-CAUGHT PACIFIC HALIBUT (*HIPPOGLOSSUS STENOLEPIS*)

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ABSTRACT

We report the results of a pilot study conducted in August and September 1992 off the east coast of Kodiak, Alaska, to evaluate a seabed cage method for estimating the post-capture survival of trawl-caught Pacific halibut (*Hippoglossus stenolepis*). Following capture, halibut were placed into cages, which were returned to the sea bottom, and then retrieved 1 or 5 days later. The number of live halibut following cage retrieval was tabulated and compared with initial numbers placed in cages to estimate post-capture survival. Primary treatment effects examined in this study were halibut density (two versus six halibut per cage) and cage soaking duration (1 or 5 days). Half of the halibut in each cage were tagged to assess potential tagging mortality. Attempts were made to standardize other factors that could influence halibut survival. Data from 32 cage deployments and retrievals were included in the analyses. Cage density and tagging did not significantly affect survival; however, post-capture halibut survival was significantly lower after 5 days' soak duration than after 1 day. Survival of post-capture halibut significantly decreased as on-deck exposure time increased from 13 to 23 minutes. Our results suggest that body condition variables (e.g., hemorrhaging) may not be very useful for predicting survival. A model that predicted survival as a function of deck exposure time and cage soak duration had an accuracy rate of 73% at the individual halibut level and greater accuracy for the sample as a whole (i.e., 78 of a total of 124 halibut were predicted to die, whereas 71 halibut actually died). We conclude that the seabed cage methodology is a useful and efficient means for determining relative survival of Pacific halibut that has considerable advantages over other methods used to assess short-term survival. However, further study is needed before absolute survival estimates can be determined using this method.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

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KEY WORDS

Alaska, bycatch, groundfish, mortality estimation, Pacific halibut, survival

INTRODUCTION

The groundfish resources off Alaska are among the richest in the world, with the long-term potential yield estimated to exceed 3.3 million metric tons annually (Megrey and Wespestad 1990). However, various fisheries in this region are adversely affected by the inadvertent catch of non-target species, hereafter referred to as "bycatch." The associated post-capture mortality of discarded bycatch species has been identified as a problem of great and increasing regional, national, and international concern (Saila 1983, NOAA 1991, Schoning et al. 1992), and Pacific halibut (*Hippoglossus stenolepis*) bycatch in the North Pacific trawl fisheries is an issue that will likely continue to grow in importance (Megrey and Wespestad 1990).

Efforts to address bycatch problems in the North Pacific have largely been focused on methods to reduce the quantities of bycatch species caught. Halibut bycatch mortality quotas, which limit the biomass of halibut that can be caught or killed in non-target fisheries by fishery, season, and area, have been employed in this region. These quotas have often resulted in the closure of certain Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI) bottom trawl fisheries before quotas of target species were attained. For example, the 1990 BSAI joint-venture flatfish trawl fishery was closed on July 1 when it was projected that the Pacific halibut bycatch limit of 800 mt had been taken, leaving approximately 48% of the groundfish quota of 258,000 mt unharvested (Williams 1991).

Williams and Wilderbuer (1991) reported Pacific halibut post-capture mortality rates in the North Pacific trawl fisheries to be 65% and 75% for the GOA and BSAI, respectively. These estimates are based on qualitative assessments of Pacific halibut condition at the time of release using methods developed by Hoag (1975). Data are collected by National Marine Fisheries Service (NMFS) observers, who examine and categorize the condition of individual halibut as "excellent," "poor," or "dead," based on physical condition and various stress indicators (Williams and Wilderbuer 1991). Annual mortality estimates are calculated by the International Pacific Halibut Commission (IPHC) using the observer-collected halibut condition data aggregated over fisheries and category-specific survival estimates first proposed by Hoag (1975) and recently revised by Williams and Wilderbuer (1991).

Category-specific survival estimates are largely based on the results of a tagging study described in detail by Hoag (1975), from which the absolute mortality of halibut in "excellent" condition was estimated using recovery rate data and a formula that required estimation of a large number of parameters (including proportion of recovered tags reported, fishing mortality rate, and disappearance rate from all sources other than fishing). Because most of the parameters employed in the estimation procedure could not be measured with certainty, the accuracy and precision of the resulting mortality estimates are unknown. Uncertainty concerning mortality estimates is exacerbated by qualitative judgments of halibut condition by observers.

The economic importance of the halibut and groundfish fisheries in the North Pacific and the biological significance of halibut post-capture mortality rates have heightened interest in obtaining more accurate and precise estimates of post-capture mortality and identifying means to enhance survival. The long-term objectives of our work are to develop improved methods for estimating survival of discarded Pacific halibut, to apply these methods to estimate survival for a variety of fishing and handling practices, and to identify practices that enhance survival.

In this report, we describe the results of a pilot study conducted in 1992 in the Gulf of Alaska. The purpose of this study was to develop, test, and evaluate a new method for estimating the post-capture mortality of Pacific halibut in which seabed cages were employed. Our approach was similar to that used by Carr et al. (1992) to estimate mortality of discarded fish off the U.S. east coast. Specific objectives of our study were to

1. evaluate the cage and sampling designs,
2. determine appropriate halibut densities within cages,
3. evaluate potential cage soaking duration effects, and
4. determine the usefulness of measures of halibut condition and other factors for predicting survival.

METHODS

Bottom trawl tows were conducted off the east coast of Kodiak Island, Alaska (57°44' to 57°53' N latitude, 151°48' to 151°55' W longitude), between 15 August 1992 and 1 September 1992 by the F/V *Royal Baron*. A four-panel Aberdeen bottom trawl supplied by the National Marine Fisheries Service was used for all tows.

In order to assess survival, halibut were placed into cages which were then lowered to the sea bottom and retrieved at a later time. Cages used in this experiment weighed 159 kg each and were truncated pyramids in shape, 1.52 m x 1.83 m at the base, 1.52 m high, and 1.07 m x 1.37 m at the top. Cage frames consisted of 1.6- and 1.9-cm hot-rolled round bar. Side and top panels were constructed of 8.9-cm knotted nylon mesh (stretched and measured between knots), whereas bottom panels consisted of knotless 6.4 cm nylon meshes (stretched-measure between crossings). Cages were marked with an identification label. Cage bottoms were detachable, allowing them to be stacked. This feature proved advantageous for transportation as well as for conservation of limited deck space.

A 2x2 experimental design (Table 1) was employed. Primary treatment effects examined were halibut density (two versus six halibut per cage) and cage soaking time (1 or 5 days). Whenever possible, the full design (i.e., deployment of all four cages) was completed for each tow. However, sufficient numbers of halibut were not always captured, which resulted in the deployment of as few as two cages per tow. In these instances, treatments (i.e., one of the rows or columns in Table 1) were selected using a random number table. Attempts were made to standardize or minimize variability in tow duration (at 1.17 hr), deck exposure time (15-20 min), and halibut size (40-80 cm), whereas other factors (e.g., catch weight, towing depth, air temperature) were recorded as continuous variables (Table 2).

After each haul, the catch within the cod-end was weighed using an electronic load cell. Species composition (percent) was visually estimated immediately after the catch was released from the cod-end and onto the deck. Halibut were randomly selected from the catch, measured (fork length, cm), and assessed for body condition. Qualitative body condition factors recorded were body movement (yes or no), operculum closure (weakly closed or tightly closed), eye condition (cloudy, clear, or hemorrhaged), gill color (red or pink), body hemorrhaging (none, minor, or major), and fin hemorrhaging (none, minor, or major). Half of the specimens were tagged using a coded plastic disk attached to a nylon wire tie fastened around the caudal peduncle. Immediately after processing, individual halibut were placed into cages in random order in accordance with the predetermined experimental design.

Cages were placed near the vessel's rail prior to landing the catch on deck and remained on the deck until all had been filled. Once processing was completed, cage doors were closed and cages were manually lifted over the side rails and released into the water in a random order. Cages were allowed to sink freely to the sea bed. We attempted to begin this cage deployment process precisely 15 min after the catch was exposed to the air. Approximately 1 minute was required to deploy each cage; hence, deck exposure times varied up to 4 min within tows.

Cages were retrieved after approximately 1 or 5 days. The live halibut taken from these cages were measured and qualitatively assessed for body condition. The tag numbers were recorded, tags were removed, and live halibut were returned to the sea. Dead halibut were counted; tag numbers and length measurements were recorded when possible.

DATA ANALYSIS

A logistic regression model was fit by the method of maximum likelihood for the binary response data (i.e., dead or live) using a logit-link function (Cox and Snell 1989). The relative significance of explanatory variables in the model was evaluated using Wald's chi-square (SAS 1989, p. 1097). The probability level for rejection of the null hypothesis (i.e., no difference in treatment levels) was set at $\alpha = 0.10$. Weighted means of survival estimates and variances were calculated as described by Seber (1982, page 6).

Maximum likelihood parameter estimates of the explanatory variables provided by the logistic regression model were computed using iteratively reweighted least squares. The model used was

$$\text{logit}(p) = \log(p / (1-p)) = \alpha + \beta'\mathbf{x},$$

where $p = \Pr(y = 1 \mid \mathbf{x})$,

y = 1 if live and 0 if dead,

α = intercept,

$\mathbf{x}$ = vector of explanatory variables, and

β' = vector of slope parameters.

Maximum likelihood estimates of p were then calculated as

$$\hat{p} = e(\hat{\alpha} + \hat{\beta}'x) / (1 + e(\hat{\alpha} + \hat{\beta}'x)).$$

The effectiveness of the model for estimating survival was tested by comparing the maximum likelihood estimate of p (i.e., $\hat{p}$) to the binary response variable (y) for each specimen. If $\hat{p}$ was greater than or equal to 0.5, then $\hat{p}$ was rounded up to 1, whereas if $\hat{p}$ was less than 0.5, the value was rounded down to 0. This technique allowed direct comparisons between the actual and predicted fates of individual fish. Classification tables then were constructed that provided the number of

1. survivors that the model correctly predicted would survive,
2. mortalities that the model correctly predicted would die,
3. survivors that the model incorrectly predicted would die, and
4. mortalities that the model incorrectly predicted would survive.

RESULTS

Halibut were caught during 11 tows, and data were obtained from 39 cage deployments and retrievals. Data produced from seven cages and one of the tows were excluded from analyses because either the soaking durations or cage densities did not conform to the experimental design.

The 2x2 design (2 levels of halibut density, and 2 cage soak duration times) was completed during each of four tows, whereas various 1x2 designs (i.e., rows or columns in Table 1) were completed during the remaining six tows. The number of cages deployed and retrieved within each cell of the design ranged from 6 to 10 (Table 1).

Although the observed soaking durations were similar to that intended for the 1-day soak (0.9 to 1.1 days), the observed values often did not correspond well to the 5-day nominal soaking duration (4.8 to 6.0 days, Table 2). Tow duration, which we attempted to fix at 1.17 hours, stayed within a narrow range of 1.17 to 1.25 hours (Table 2). Halibut size was successfully restricted within the intended size range of 40-80 cm fork length. However, observed deck exposure times were slightly outside the intended minimum and maximum values for some tows and ranged from 13 to 23 minutes (Table 2). Minimum, maximum, and average values for other factors that were not standardized and were measured as continuous variables are reported in Table 2. Of those factors measured, only catch weight had a coefficient of variation greater than 0.17 (i.e., 17%).

We did not detect a significant effect of cage density on survival of Pacific halibut (Table 3). The power of this test ($1 - \beta$) is approximately 0.58 for a difference in survival of 20% between the two densities. Statistically significant differences were observed, however, between cage soaking durations (Table 3), with the 5-day soaking duration producing lower mean survival rates than the 1-day soak (Fig. 1). No significant interaction occurred between cage soaking duration and density (Table 3). In subsequent analyses, data were pooled across cage densities because of the lack of significant main and interaction effects.

All specimens examined exhibited some level of body movement and had clear eyes and red gills. The lack of variation in these factors precluded their use to predict survival. The number of fish examined with minor or major cuts, body hemorrhaging or fin hemorrhaging, and their observed survival rates for each category, are reported in Table 4. Minor and major categories were combined for purposes of logistic regression analysis because insufficient sample sizes (5 or less observations per cell) were obtained for some of the individual categories. Of the condition factors examined, the ability to close the operculum was the only factor that had a significant effect on survival after both 1-day and 5-day soaking durations (Table 4). However, whereas a weakly closed operculum was a good predictor of low survival (25% and 0% survival for 1- and 5-day soaking durations, respectively), halibut exhibiting tightly closed operculi did not necessarily survive well (67% and 34% survival for 1- and 5-day soaking durations, respectively). Results for the other condition factors were not significant, and the differences seen were sometimes inconsistent with expected results (e.g., increased survival was observed for fish with increased hemorrhaging).

The logistic regression analysis performed to estimate the effects on survival of quantitatively measurable variables included cage density, soak duration, deck exposure time, tagging (tag present or absent), fish length, and catch weight. Of these variables, only cage soaking duration and deck exposure time were found to have significant effects on halibut survival (Table 5).

The relationship between halibut survival and on-deck exposure time is shown in Figure 2. Survival decreased rapidly with increased deck exposure time for both 1- and 5-day soaking durations, and approached zero following approximately 20 min of exposure. Variation in survival was highest and mean survivals were lowest for the 5-day soaking duration estimates.

Inclusion of only deck exposure time and cage soaking duration in the logistic regression model (Table 6a) resulted in correctly predicting the fate of individual halibut 73% of the time (Table 6b). Incorrect prediction rates were nearly equal for false positives (i.e., 28% of the individuals predicted to survive actually died) and false negatives (25% of the individuals predicted to die actually survived). The model was extremely effective at predicting the overall fate of halibut for the trip (i.e., 78 of a total of 124 halibut examined were predicted to die, whereas 71 halibut actually died).

DISCUSSION

The major objective of this pilot study was to evaluate the seabed cage methodology as a tool to estimate survival of Pacific halibut. Thus, attempts were made to standardize most variables that could influence halibut survival to increase the probability of detecting potential effects of cage densities, soaking durations, and tagging. Desired levels of variation were achieved for most standardized variables, with the exception of the 5-day cage soaking duration (actual levels were 4.8 to 6.0 days) and deck exposure time (13 to 23 min). Poor weather conditions forced us to leave some cages on the seabed for 1 day longer than planned, and our control over deck exposure time increased as we gained experience.

Cage density and tagging did not significantly affect Pacific halibut survival, which simplifies planning and execution of future work. Subsequent study phases can be conducted using up to six halibut per cage. The ability to tag and identify individuals without affecting survival will enable us to test the effects of certain variables (e.g., body condition, halibut size) that otherwise could not be tested.

Post-capture halibut survival was significantly lower after 5 days' soaking duration than after only 1 day, preventing us from confidently estimating absolute survival from these results. However, the fact that the interaction term between cage soaking duration and density was not significant suggests that the described methodology is appropriate for determining relative survival estimates.

The difference in survival between cage soaking durations implies either (1) it requires more than 1 day to account for all trawl-related mortality (i.e., mortality is delayed), (2) confinement in cages causes mortality, or (3) some combination of the two. Neilsen et al. (1989) suggested that 48 hr was sufficient for establishing survival of trawl-caught and released Atlantic halibut (*Hippoglossus hippoglossus*), but they did not actually demonstrate that this was the case. The differences we observed in survival between cage soaking durations demonstrates the need for further study before absolute survival estimates can be obtained.

One potential confinement-related mortality factor is predation by amphipods known locally as "sand fleas." The flesh of many halibut retrieved from cages in this study had been consumed by amphipods prior to cage retrieval. We are uncertain whether amphipods successfully attacked live, healthy halibut that otherwise could have escaped under less confining conditions, or simply scavenged upon individuals killed or weakened by trawling-related injuries and stress. Amphipod attacks have been reported for various marine species confined within cages or restricted on longlines (Hart 1942, Scarratt 1965, Templeman 1967). However, Templeman (1967) demonstrated that healthy American lobster (*Homarus americanus*) were able to resist attacks unless movement was severely restricted. Our cages were designed to allow ample area for halibut movement with this potential problem in mind, and live halibut were retrieved in excellent condition from cages that also contained halibut devoured by amphipods. Ancillary evidence suggests that short-term confinement of halibut within cages is not deleterious. Peltonen (1969) found that Pacific halibut held in cages on the sea bottom remained in excellent condition after a period of 1 month without food, although the cages used were larger and placed in shallower water than those used in this study.

Survival of post-capture halibut decreased rapidly as deck exposure time increased over a narrow range of only 13 to 23 min. The slopes of the regressions for the two soak durations were similar, suggesting that the rate of decline across deck exposure times does not vary with soaking duration. We estimated that once deck exposure time begins affecting halibut survival, survival rates decrease approximately 8% per minute until halibut are returned to the sea. Hoag (1975) found that of several factors examined, time on deck had the greatest effect on Pacific halibut condition. Similar relationships between survival and deck exposure time have been established for other trawl-caught and released species such as Atlantic halibut (Neilson et al. 1989), Atlantic cod (*Gadus morhua*) and American dab (*Hippoglossoides platessoides*) (Jean 1963), and red king crab (*Paralithodes camtschaticus*) (Stevens 1990). Carr et al. (1992) demonstrated significant increases in blood lactate concentrations with increased deck exposure times for Atlantic cod and American plaice (dab). The time at which deck exposure begins adversely affecting Pacific halibut and the rate at which survival decreases across deck exposure times probably vary as conditions change (e.g., presence or absence of sea water on deck, temperature, humidity, fish size). Nevertheless, our results demonstrate the importance of quickly returning halibut to sea to enhance the probability of survival.

Clearly, accurate survival estimates of post-capture halibut are important for stock assessment and management purposes. The current method used to estimate discarded halibut survival relies heavily on qualitative assessments of fish condition based upon fish appearance. However, our results suggest that the body condition factors we examined may not be very useful for predicting survival. Although individuals with weakly closed operculi typically died (10 of 12 individuals with this condition died), the ability to close the operculum tightly was not a consistent predictor of survival. All other condition factors examined did not have a significant effect on survival. Neilson et al. (1989) reported that Atlantic halibut judged to be in excellent physical condition using Hoag's (1975) criteria often exhibited delayed mortality, and noted the potential danger of basing survival estimates on qualititative assessments. We emphasize, however, that additional field work is needed in order to fully assess the predictive value of condition factors.

Another problem associated with predicting survival based solely on judgments of physical condition by observers includes the potential for qualitative assessments to vary among observers because of differences in experience. In addition, the ramifications of these qualitative assessments for the trawl fleet may place the observers in a tenuous position, particularly when a bycatch quota is close to being reached.

In contrast to our results for qualitatively determined condition factors, we found that a model based on quantitatively measurable factors including deck exposure time and cage soaking duration resulted in highly accurate predictions of halibut survival (i.e., the model predicted that 78 of 124 halibut placed into cages would die, whereas the actual mortality rate was 71 of 124 halibut). In future phases of this study, we plan to examine a wider range of variables that may potentially influence survival, including tow duration, season, catch weight, etc. Subsequently, we will develop an expanded predictive model incorporating those variables with significant effects on survival. The accuracy of post-capture survival estimates from the resultant expanded model will then be compared with estimates based on qualitative observations of physical condition.

A potential problem of using the seabed cage methodology for estimating survival is limited deck space on board fishing vessels, because numerous cages are required for this type of research. For example, if the minimum soak time required to detect trawl-induced mortality was 5 days, and if a 3x3 design was employed, then the experiment would require nine cages to complete a single block. If one block was completed per day, then 45 cages would be required for efficient use of chartered vessel time. We addressed this potential problem by using stackable cages to conserve deck space and by storing cages on the sea bottom until needed. We also note that limited deck space is a problem that is not unique to cage studies, and may be more difficult to address for alternative study methods. For example, only a small number of live-tanks can be accommodated aboard most vessels, which severely constrains the number of treatment effects and samples sizes that can be obtained per day when live-tanks are used to assess short-term survival. Because the largest expense of this type of study is chartered vessel time, the ability to obtain significant results (or results that are not significant with high power) with minimal sampling effort is of considerable importance.

Holding fish in tanks on board vessels, which has been commonly employed in short-term survival studies (e.g., Jean 1963, de Veen et al. 1975, Stevens 1990), introduces a host of artificial conditions that are not normally experienced by discarded species. The seabed cage method provides an environment more similar to that experienced by discarded fish than does the use of live-tanks, but the method still involves confinement. Use of acoustical tags to assess survival of fish released into the environment unconstrained, as employed by Jolly and Irby (1979), could provide more realistic survival estimates than the seabed cage methodology, but the attainment of adequate sample sizes needed to detect significant differences among potential explanatory variables could be problematic.

We conclude that the seabed cage methodology is a useful and efficient means for determining relative survival of Pacific halibut that has considerable advantages over other methods used to assess short-term survival. However, further study is needed before absolute survival estimates can be determined using this method.

Future Work

While we have demonstrated the utility of the seabed cage methodology for estimating relative survival of post-capture halibut, further study is needed in order to meet our objectives of determining the relative effects of a broad range of factors of survival, and to estimate absolute survival. We have not yet determined the cage-soaking duration needed to detect all trawl-induced mortality, nor have we determined whether confinement of halibut in cages contributes to mortality (e.g., through increased vulnerability to amphipod predation). We plan to conduct three additional field studies, one during 1993 in the Gulf of Alaska and two during 1994 in the Gulf or the Bering Sea, or both. We will evaluate the effects of a wider range of soaking durations (1 to 7 days) on survival and introduce "cage controls" during the next field season. Cage controls will be developed by modifying some cages to function as traps. Williams et al. (1982) demonstrated that side-entry Tanner crab pots were effective in trapping Pacific halibut. Use of cage controls will allow us to compare the survival of trawl-caught and discarded halibut with that of halibut that have not been subjected to the trawl-capture process but are held under similar conditions. This will enable us to provide estimates of absolute, as well as relative, survival and provide a direct assessment of the extent of confinement-induced mortality.

We also plan to tag and release halibut equipped with sonic transmitters. This will provide a second control group, and thus an independent estimate of absolute survival for a limited range of explanatory variables. Underwater video will also be employed to examine the behavior of halibut within the cages and to determine whether amphipods attack live, healthy fish.

Once the remaining questions surrounding this methodology are answered, the remaining field work will be dedicated to evaluating the effects of more realistic ranges of potential explanatory variables on halibut survival (e.g., towing speed, depth, catch size, handling methods, season, vessel size, body length). Models containing significant explanatory variables will be developed to predict survival; the predictive performance of these final models will be evaluated and compared to predictions based on visual assessments of halibut condition. Identification of important explanatory variables affecting survival (that are both measurable and controllable) has the potential to enhance the survival of halibut discarded during commercial fishing operations. Recording of measurable factors that influence survival rather than qualitative judgments of halibut condition may relieve pressure on observers and provide skippers with information on methods that can be employed to enhance the survival of bycatch (e.g., reduced towing duration, reduced deck exposure time, improved handling methods). The model we will develop can be used to predict survival at the individual vessel level, which through appropriate management measures could provide a vessel-level incentive to employ fishing and handling practices that would enhance halibut survival.

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FIGURES

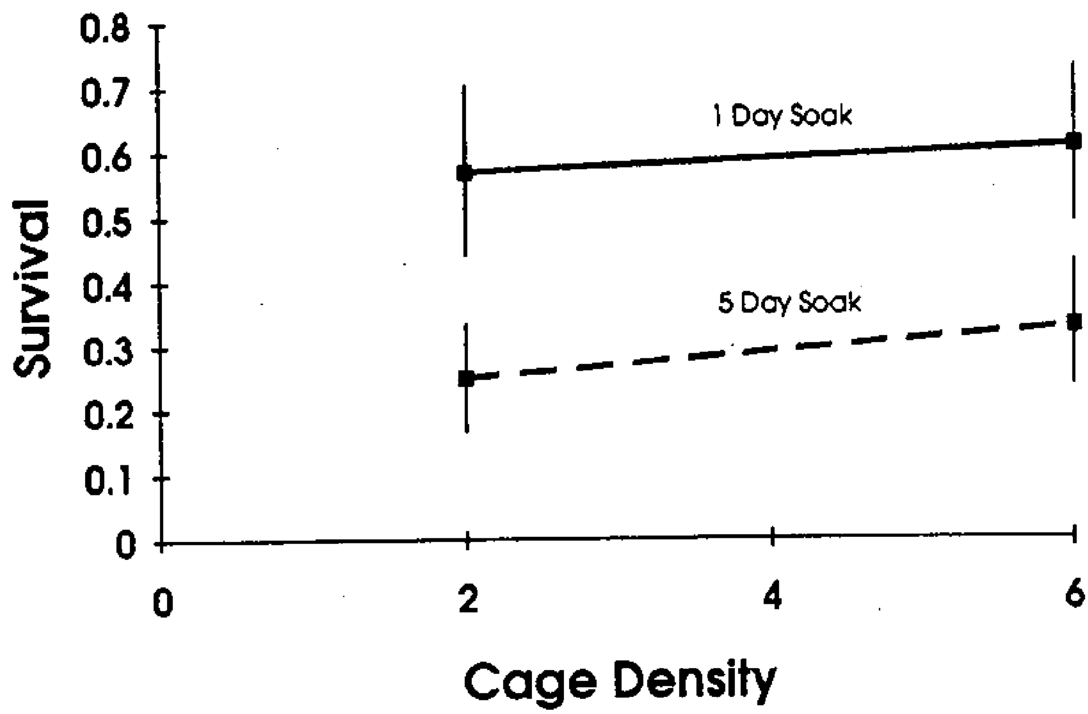

Figure 1. Mean survival of Pacific halibut (*Hippoglossus stenolepis*) for two cage densities and cage soaking durations (days). Error bars represent one standard error.

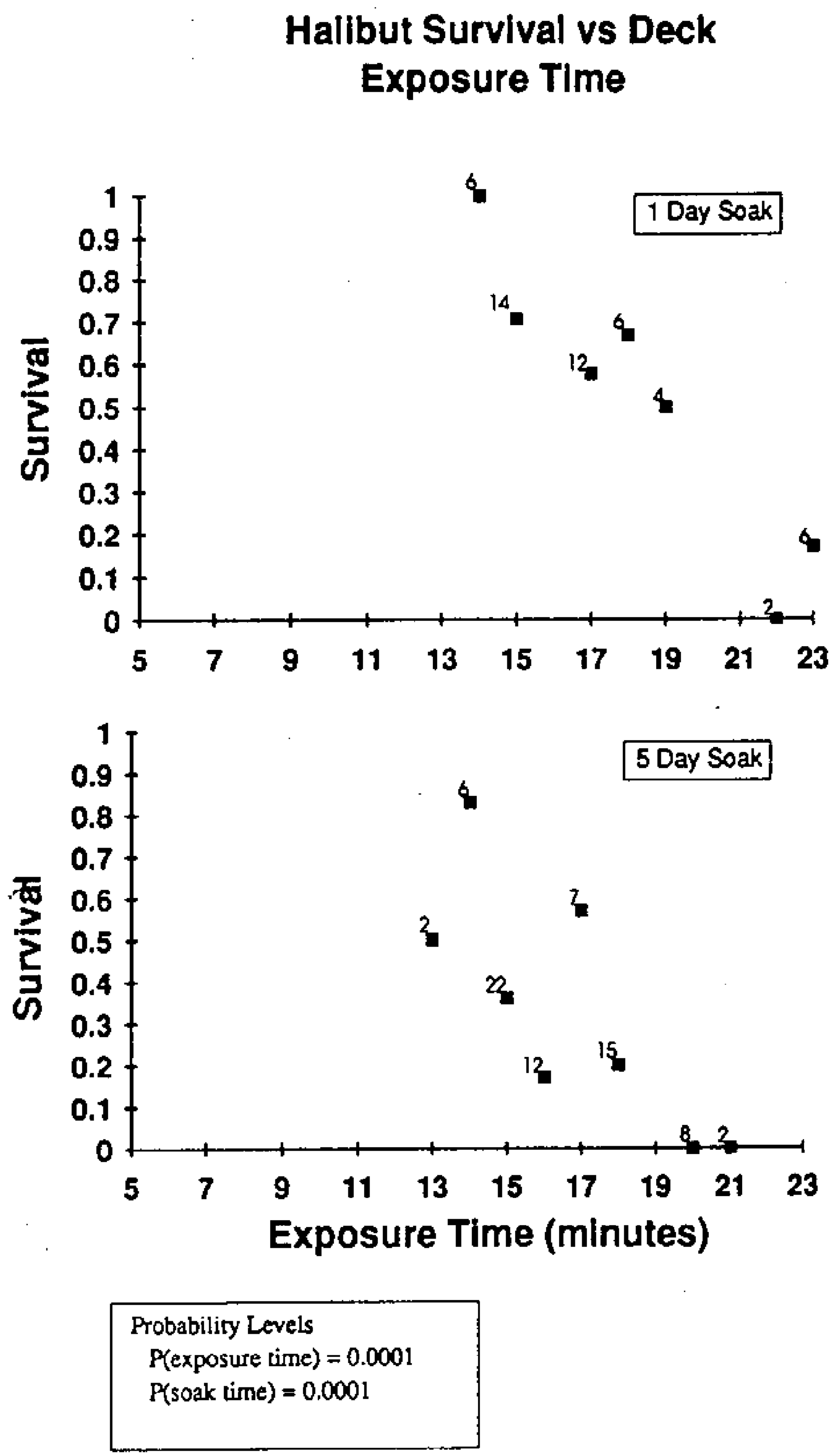

Figure 2. Mean survival of Pacific halibut (*Hippoglossus stenolepis*) versus deck exposure time (minutes) by soaking duration (days). Number of fish examined for each deck exposure time is indicated.

TABLES

Table 1. Experimental design employed to evaluate the effects of cage density and cage soaking duration on Pacific halibut (*Hippoglossus stenolepis*) post-capture survival. Sample sizes obtained (i.e., number of cages deployed and retrieved) are indicated within the second and third columns.

Cage soak duration (days)	Density (no. halibut/cage)	
	2	6
1	7	6
5	10	9

Table 2. Selected explanatory variables measured for evaluation of effects on Pacific halibut (*Hippoglossus stenolepis*) post-capture survival. Nominal values (i.e., values we attempted to standardize; NA = not applicable), sample sizes (included in the analyses), and observed minimum, maximum, and mean values, and coefficients of variation (CVs) are provided.

Variable	Nominal value	Observed				
		N	Minimum	Maximum	Mean	CV
Density (no. of halibut)	2	17 cages	2	2	2	0
Density (no. of halibut)	6	15 cages	6	6	6	0
Soak duration (days)	1	13 cages	0.9	1.1	1.0	0.03
Soak duration (days)	5	19 cages	4.8	6.0	5.5	0.09
Deck exposure time (min)	15–20	10 tows	13	23	16.8	0.14
Fork length (cm)	40–80	124 fish	40	80	55.4	0.17
Towing duration (hr)	1.17	10 tows	1.17	1.25	1.18	0.03
Catch weight (kg)	NA	10 tows	311	6,250	1,283	1.38
Towing speed (knots)	NA	9 tows	2.5	3.0	2.83	0.09
Depth (m)	NA	7 tows	55	93	69	0.12
Air temperature (°C)	NA	8 tows	50.0	59.0	55.1	0.05
Relative humidity (%)	NA	8 tows	78.0	100.0	88.6	0.10

Table 3. Effects of cage soaking duration, cage density, and interactions of these two factors on Pacific halibut (*Hippoglossus stenolepis*) post-capture survival. Data were fit using logistic regression analysis. Data from ten hauls were included in this analysis.

Variable	Chi-square	P
Intercept	0.39	0.53
Soaking duration	3.58	0.06
Density	0.64	0.42
Soak x density	<0.01	0.99

Table 4. Number of halibut observed with various body conditions, category-specific survival rates, and results of logistic regression analysis for evaluation of the relationship between body condition and survival. Data for minor and major categories for cuts, body hemorrhaging, and fin hemorrhaging were combined prior to analysis. Thus, significance levels reported are for the comparison of survival rates between "none" and combined categories. Body movement, eyes, and gill color were excluded from this analysis because all halibut examined exhibited some body movement and had clear eyes and red gills.

Condition		No. live	No. dead	% live	P
1-DAY SOAKING DURATION					
Operculum	T. closed	28	14	67	0.0279
	W. closed	2	6	25	
Cuts	None	30	20	60	—
	Minor	0	0		
	Major	0	0		
Body hemorrhaging	None	11	9	55	0.5563
	Minor	13	10	57	
	Major	6	1	86	
Fin hemorrhaging	None	8	7	53	0.5304
	Minor	9	10	47	
	Major	13	3	81	
5-DAY SOAKING DURATION					
Operculum	T. closed	23	45	34	0.0303
	W. closed	0	6	0	
Cuts	None	21	46	31	0.8793
	Minor	2	4	33	
	Major	0	1	0	
Body hemorrhaging	None	8	14	36	0.5263
	Minor	10	27	27	
	Major	5	10	33	
Fin hemorrhaging	None	6	13	32	0.9567
	Minor	11	27	29	
	Major	6	11	35	

Table 5. Results of logistic regression analysis to examine effects of deck exposure time, cage soaking duration, cage density, tagging, body length, and catch weight on Pacific halibut (*Hippoglossus stenolepis*) post-capture survival.

Variable	Parameter estimate	SE	Chi-square	P
Intercept	6.56	2.30	8.15	<0.01
Exposure time	-0.44	0.11	14.90	<0.01
Soaking duration[a]	-1.91	0.49	15.04	<0.01
Density[a]	0.07	0.48	0.02	0.88
Tag[a]	-0.60	0.43	1.99	0.16
Length	0.03	0.02	1.70	0.19
Catch weight	<-0.01	<0.01	0.03	0.95

[a]Levels were soaking duration (0 = 1 day, 1 = 5 days), density (0 = 2 halibut, 1 = 6 halibut), and tag (0 = not tagged, 1 = tagged).

Table 6. (A) Effects of deck exposure time and cage soaking duration on Pacific halibut (*Hippoglossus stenolepis*) post-capture survival, and (B) a 2x2 classification table illustrating the effectiveness of the model for predicting the fate of individual specimens. Data were fit using logistic regression analysis.

A

Variable	Parameter estimate	SE	Chi-square	P
Intercept	7.79	1.87	17.36	<0.01
Exposure time	-0.43	0.11	15.88	<0.01
Soaking duration[a]	-1.69	0.45	14.22	<0.01

B

		Predicted		
		Live	Dead	Total
Observed	Live	33	20	53
	Dead	13	58	71
Total		46	78	124

[a]Levels were soaking duration (0 = 1 day, 1 = 5 days).