


MEMORANDUM

TO: Council, SSC and AP Members

FROM: Clarence G. Pautzke
Executive Director 

DATE: April 4, 1996

SUBJECT: Ban on night trawling for Pacific cod

ESTIMATED TIME 6 HOURS (for all C-1 items)
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Review previous reports on this issue and provide further direction.

BACKGROUND

At its last meeting the Council indicated that it wished to re-examine the issue of a ban on night trawling for cod as a means to reduce halibut bycatch in that fishery. A proposal to ban night trawling was discussed by the Council in 1993, and they decided not to proceed with such a ban. A discussion paper April 1993 on this issue is included here as Item C-1(b)(1). Although studies to date indicate that halibut bycatch rates in the cod fisheries are higher at night, and some savings could be expected, the Council did not proceed with the proposal, primarily because of enforcement concerns. Item C-1(b)(2) is a copy of the 1993 letter from NMFS Enforcement Division, which outlines the reasons for their advice that such a ban would be unenforceable.

Item C-1(b)(3) is a recent letter from the IPHC (dated April 2, 1996) which addresses the Council's current considerations of this proposal. They reiterate the earlier findings that cod come off the bottom at night, and that a cessation of night trawling would reduce bycatch of halibut and crab, perhaps as much as 15%, and increase the CPUE for cod. However, they also note the potential implementation problems with this proposal; in addition to enforceability, they cite the difficulties associated with very short daylight hours during much of the year, and the potential allocative implications of increased cod catches associated with this proposal. Their letter requests that the Council weigh the possible benefits of this program against the benefits of alternative programs such as the VBA proposal.

Item C-1(b)(4) is a copy of the report from the IPHC concerning differences in bycatch rates between day and night trawling.

**Ban on Trawling for Pacific Cod at Night
Discussion Paper**

Background

At the January 1993 meeting, the Council received a proposal from the Midwater Trawlers Cooperative to ban trawling for Pacific cod at night in the BS/AI. It was felt that this action would reduce the bycatch of halibut in the trawl fishery, thus allowing more groundfish to be harvested prior to halibut PSC closures. The Council requested that preliminary information be available for discussion of this proposal at the April meeting. This paper summarizes the scientific studies on the day/night bycatch rates of halibut and identifies some enforcement concerns and other issues for consideration.

Biological Basis

Analysis of 1986 and 1987 Bering Sea JV bottom trawl fisheries indicated day/night differences in halibut bycatch rates, due to changes in relative abundance of target species and halibut (Adlerstein 1991). Walleye Pollock and yellowfin sole catches were more often than not associated with lower bycatch rates at night, while Pacific cod and rock sole tended to be associated with higher rates at night. The only consistent result was that the bycatch rates of halibut in catches associated with Pacific cod were higher at night.

Analysis of 1990 Bering Sea domestic bottom trawl fisheries indicated that bycatch of halibut would be reduced if night trawling was banned for Pacific cod, in particular (Adlerstein 1992). Halibut bycatch rates were higher at night for all areas and months examined. For example, in the area 511 directed cod fishery, the average halibut bycatch rate at night was 1.61 times the day rate.

Further analysis of the 1990 domestic bottom trawl fisheries in area 511 indicated that day-only trawling may reduce total halibut bycatch by 13% (Adlerstein and Trumble 1993). Alternatively, without a reduction in bycatch, groundfish harvest could be increased by about 13%. A night trawling ban may also reduce the bycatch of King crab by 13% and Tanner crab by 16% (Adlerstein and Trumble 1993).

Enforcement Concerns

A plan amendment that would ban trawling at night has potential enforcement problems, especially if the ban is not required for all trawl fisheries. Apparently, there would be no practical way to enforce the proposal short of banning all trawling at night or prohibiting the retention of any Pacific cod taken at night. In the latter case, waste could be substantially increased with little or no decrease in removal. Effective enforcement of the retention ban would be difficult at best (Dave Flannagan, NMFS Enforcement Division, personal communication). Because Directed

Fishing Standards are percentages based on trip or weekly landings, this proposal would not prohibit targeting on Pacific cod at night. An amendment to ban targeting on Pacific cod at night would also be difficult to enforce. There would be virtually no way to prove a violation short of a confession (Dave Flannagan, pers. comm.).

Other Considerations

A ban on night trawling may raise allocative issues. For example, a night ban for cod would allow trawlers to harvest more cod per unit of halibut bycatch, and thus may increase the total amount of cod and other groundfish caught by trawlers. If the 1990 data for area 511 are representative, bottom trawlers could harvest up to 13% more Pacific cod. In turn, the amount of cod available for harvesting by other gear types would be reduced.

There may be some economic issues to consider. Vessels may incur some costs associated with not trawling for cod at night. Added costs may be incurred with increasing travel time, lost fishing opportunities, and moving to avoid cod concentrations at night. The costs may differ between vessel sizes, proximity to the fishing grounds, and fishing seasons (quarters).

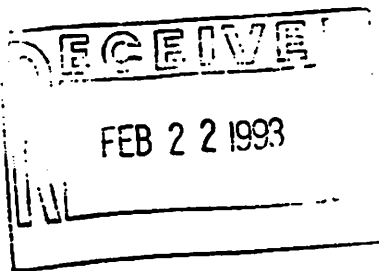
Because the amount of daylight in the Bering Sea area varies by season, with much fewer hours of daylight in the winter, allowed fishing times will need to be set on a seasonal basis. For example, at 55° N Latitude, daylight ranges seasonally from about 18 hours in June to only 6 hours in December. If fishing were allowed only during daylight hours, effort would be severely restricted in the winter months. Perhaps a set number hours for each season (quarter) would be more appropriate than daylight hours.

Literature Cited

Adlerstein, S. 1991. Comparison of day and night bycatch rates in Bering Sea joint venture bottom trawl fisheries. Report on Commission Activities, 1991:81-91. International Pacific Halibut Commission.

Adlerstein, S. 1992. Comparison of day and night bycatch rates in Bering Sea domestic bottom trawl fisheries. Report of Assessment and Research Activities, 1991:211-219. International Pacific Halibut Commission.

Adlerstein, S.A., and R.J. Trumble. 1993. Management implications of changes in by-catch rates of Pacific halibut and crab species caused by diel behaviour of groundfish in the Bering Sea. ICES Marine Science Symposium 196:199-203.



UNITED STATES DEPARTMENT OF COMMERCE
N.O.A.A. / National Marine Fisheries Service
Alaska Enforcement Division
P.O. Box 21668
Juneau, Alaska 99802-1668

February 16, 1993

Mr. David Witherell
North Pacific Fishery
Management Council
P.O. Box 103136
Anchorage, AK 99510

RE: Night Ban On Trawling For Pacific Cod

Dear David,

Thank you for the opportunity to comment on the proposed amendment to prohibit night trawling for Pacific cod in the BS/AI. Although the rationale behind the proposal may be sound, I cannot perceive of any practical way to implement or enforce the proposal short of banning all trawling at night or prohibiting the retention of any Pacific cod taken at night. In the latter case, waste is substantially increased with little or no decrease in removals. Effective enforcement of the retention ban would be difficult at best.

I am presuming that the proposal is to prohibit "directed fishing" for Pacific cod at night. Under current regulations, a directed fishery is defined by our "Directed Fishing Standards". These standards are based on the amount of retained fish during a fishing trip (or weekly reporting period in the case of at-sea processing vessel). These standards do not prohibit a vessel from targeting on any particular bycatch species as long the retained catch of the bycatch species does not exceed a designated percentage of all other retained catch aboard the vessel during the trip. If we are going to pursue the "directed fishing" scenario, all concerned must realize that the regulation will not prohibit targeting on Pacific cod at night and there is virtually no way to prove a violation short of confession. Under our current definition of a trip, I don't believe a violation of this proposal is even identifiable.

For any regulation to be enforced a violation must at least be detectable through one or more standard enforcement or monitoring mechanisms. These being surveillance, boarding and inspection, records auditing, investigations, on board informants, or observer coverage. Effective enforcement is that which results in substantive compliance. Effective enforcement generally only occurs when a violation can be detected by multiple enforcement

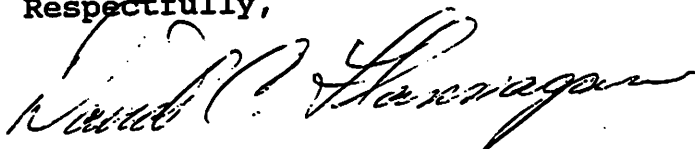


mechanisms and the resources to carry out enforcement and monitoring are sufficient to routinely detect obvious violations. Violations of this proposal cannot be detected through any of our standard enforcement or monitoring mechanisms. Observers and on board informants do not have the practical ability to monitor amounts of retained product. They certainly do not have the ability to adequately account for product retained at night versus all other times of the day. Observer sampling procedures focus on total catch. Even a cod end containing 100% Pacific cod which is retrieved in the dead of night and processed would not constitute a violation of directed fishing standards. Logbooks also provide no means of detecting a violation. Logbooks reflect total retained product for the entire day. They do not address production during any particular segment of the day.

Lastly, I do not believe that the regulation can be remedied by redefining a trip to be that period of time between sundown and sunrise. Production numbers for such a short period of time would be difficult for any vessel to accurately obtain. Record keeping would be greatly exacerbated for the vessel. Further production data for such a short period of time is easily manipulated and almost impossible for enforcement or anyone else to verify.

I have discussed this issue with Capt. Anderson of the 17th CGDIST and he concurs that this proposal is unenforceable. Please contact me if you have any questions or any other thoughts as to how such a ban might be effectively implemented.

Respectfully,



David C. Flannagan
Special Agent in Charge

cc: 17CGDIST-B. Anderson
F/AKR-R. Berg
R. Hegge

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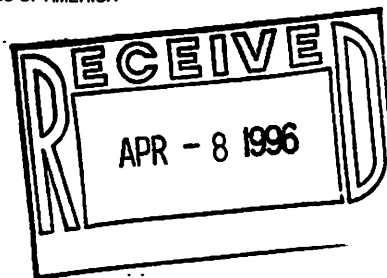
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ESTABLISHED BY A CONVENTION BETWEEN CANADA

AND THE UNITED STATES OF AMERICA



April 2, 1996

Dr. Clarence Pautzke, Executive Director
North Pacific Fishery Management Council
605 W 4th Avenue Room 306
Anchorage AK 99501

Dear Clarence:

At the April meeting, the Council is scheduled to review information available on day-night differences in halibut bycatch rates in Pacific cod trawl fisheries, as part of an evaluation of a ban on night-trawling for Pacific cod. Data analysis by the staff of the International Pacific Halibut Commission (Adlerstein 1992; Adlerstein and Trumble 1993) has indicated that significant day-night differences occur in the catch and bycatch rates for the Pacific cod-pollock trawl fishery, based on data from 1990 (for which adequate data existed at the time of the analysis). At the time of the analysis, Pacific cod and pollock were combined as a target fishery.

Calculation of the changes in bycatch that may result from a ban on night trawling depends on two factors: the bycatch rate and the amount of catch that occurs at night. We believe that the information in the IPHC reports adequately captures the bycatch rate. Pacific cod come off the bottom at night, reducing groundfish CPUE; night hauls tend to catch larger halibut, probably because halibut cannot avoid trawls in darkness; and crabs tend to pod at night and burrow during the day. This basic biological behavior should remain consistent. The proportion of night trawling, however, may be quite variable as vessel captains adjust their operations to fishing and market conditions. The absolute amount of bycatch reduction depends on the relative amount of the day and night catch occurring in the fishery.


Day-only trawling will reduce overall halibut and crab bycatch rates in the Pacific cod fishery. Night-time catch per unit effort of Pacific cod dropped compared to day CPUE (Figure 1 from Adlerstein and Trumble): day-time CPUE (catch per hour) averaged about 20-50% higher than night-time values. Night-time bycatch rates of Pacific halibut, king crab, and Tanner crab (Figure 1) were consistently higher than rates during the day (5-15% for halibut), although not statistically significant. For 1990 in Area 511, day-only trawling would have reduced halibut bycatch by about 13%, king crab bycatch by 13%, and Tanner crab bycatch by 16%.

After our experience with grid sorting, we recognize that ideas that seem worthwhile often do not stand up under current fishing, enforcement, and management practices. The discussion paper, "Ban on Trawling for Pacific Cod at Night," from the April 1993 Council meeting summarized several concerns to be addressed if an analysis of this proposal goes forward. 1) NMFS Enforcement indicated that a night ban is practically unenforceable. 2) The night duration changes daily, longer in winter and shorter in summer, so "night" may need an arbitrary definition in the regulations. (Additionally, cloud cover extends the effective period of darkness.) 3) Short daylight hours in winter will severely restrict fishing, which will generate economic issues. 4) Increased harvest in the Pacific cod fishery will have allocative effects for the remainder of the trawl fishery.

As the Council makes its decision whether to move forward with a proposal for a night ban, we request that you consider the following factors: 1) will any projected bycatch savings be used to reduce bycatch mortality limits, to increase groundfish harvest, or for both; 2) will the savings from a night ban be just as likely under a Vessel Bycatch Account program; and 3) will analysis of a night-trawl ban slow down work on the VBA program, which could more directly affect bycatch savings?

We support efforts to reduce halibut bycatch and to maintain groundfish harvest. However, we believe that the most productive bycatch reduction program will involve effective individual incentives. We recommend that the Council put maximum effort into overcoming the obstacles to an incentive program such as the Vessel Bycatch Account (VBA). Under a VBA, fishermen will readily make the decision not to trawl at night if night-time bycatch adversely affects their use of bycatch mortality.

Sincerely,



Donald A. McCaughran
Director

cc: Commissioners

ICES mar. Sci. Symp., 196: 211-215. 1993

Management implications of changes in by-catch rates of Pacific halibut and crab species caused by diel behaviour of groundfish in the Bering Sea

Sara A. Adlerstein and Robert J. Trumble

Adlerstein, S. A., and Trumble, R. J. 1993. Management implications of changes in by-catch rates of Pacific halibut and crab species caused by diel behaviour of groundfish in the Bering Sea. - ICES mar. Sci. Symp., 196: 211-215.

This study compares day and night by-catch rates of prohibited species (ratio of prohibited species to groundfish catch) in US domestic bottom-trawl fisheries for Pacific cod (*Gadus macrocephalus*) and walleye pollock (*Theragra chalcogramma*) in the Bering Sea to identify management options to reduce by-catch. Bottom trawl fisheries in the Bering Sea cause significant by-catch mortality of Pacific halibut (*Hippoglossus stenolepis*) and other prohibited species such as king crab (*Paralithodes camtschatica*) and Tanner crabs (*Chionoecetes* spp.) By-catch rates are higher during night hours than during the day. We propose that by-catch differences are caused by diel vertical migration and other behavioural characteristics of the species that result in fluctuations of their relative abundance near the seabed between the two time periods. Avoiding night bottom fishing in the Pacific cod and walleye pollock fisheries may permit by-catch rate reduction. Fishing exclusively during day hours could produce total savings from 13 to 16% of the observed by-catch of halibut, king crab, and Tanner crabs.

Sara A. Adlerstein and Robert J. Trumble: International Pacific Halibut Commission, PO Box 95009 Seattle WA 98145-2009, USA.

Introduction

By-catch of prohibited species such as Pacific halibut (*Hippoglossus stenolepis*), king crab (*Paralithodes camtschatica*), and Tanner crabs (*Chionoecetes* spp.) in the Bering Sea causes tremendous losses, both in groundfish and in prohibited species fisheries. Management regulations for by-catch in the region set quotas for prohibited species (tonnes of halibut and number of crabs) in the various groundfish fisheries and require prompt discard of the by-catch to the ocean. By-catch quotas are often reached before the groundfish quotas are taken, and these fisheries are closed before their allowances are harvested. Among the bottom trawl fisheries in the region, catches with high proportion of Pacific cod (*Gadus macrocephalus*) experience high halibut by-catch rates. Fishermen have reported that higher by-catch rates occur during night hours than during the day. Variation in these rates is most probably related to the diel vertical migration of Pacific cod. Cod species, usually found in close association with the seabed during day hours, have been reported to migrate to the surface

during the night (Beamish, 1966; Turuk, 1973). The goal of this study is to investigate the reported day and night differences in by-catch rates and to understand the behavioural processes of the various species involved in the fishery to use this information for management purposes. Our approach was statistically to compare fishery data, and to complement the results with biological information on the species' behaviour.

Material and methods

Pacific halibut and crab species by-catch rates vary with the composition of the groundfish species in the catch (i.e. walleye pollock (*Theragra chalcogramma*), Pacific cod, yellowfin sole (*Limanda aspera*), rock sole (*Lepidopsetta bilineata*) and other flatfish) (Berger *et al.*, 1989; Clark, 1990; Adlerstein, 1991). This analysis investigates whether by-catch rates in the Pacific cod and walleye pollock fisheries vary from day to night after accounting for systematic changes in species composition in the catch. The study uses data from individual

bottom trawl hauls from the 1990 domestic operations in the western region of Area 511 in the Eastern Bering Sea (Fig. 1). Pacific cod is part of several bottom-trawl multispecies fisheries and is an important component of the total catch of Pacific cod and walleye pollock fisheries. Fishing operated in the area from January to May. Pacific cod is also caught by trawls in Areas 513, 517, 519, 521, and 522, but we selected Area 511 because of data availability. Data were provided by the National Marine Fisheries Service (NMFS), Seattle, and are from a haul by haul database collected by observers in the North Pacific and Bering Sea (NORPAC) generated by a mandatory observer programme. Records contain the weight, numbers, and length frequencies of Pacific halibut, number of crabs, total catch weight, and weight by groundfish species. Records also contain information about trawl operations such as gear type, date, location, and time of set and retrieval of the nets. Day hauls are those set and retrieved between sunrise and sunset, and night hauls are those taken after evening twilight and before morning twilight. Hauls extending from day to night periods were classified as transitional.

Comparison of day and night rates used an analysis of covariance (ANCOVA) (Zar, 1984), where by-catch rates are a function of the catch composition. The analysis used the Generalized Linear Interactive Modelling (GLIM) System (Royal Statistical Society 1987). The proportions of Pacific cod and rock sole in the catch were incorporated as covariates, and month (January to May) and time period of the day were included as fixed factors. Walleye pollock, an important component of the catch, was not included as a covariate because Pacific cod and pollock are collinearly related in these fisheries

(Adlerstein, 1991). Yellowfin sole, another important component of the overall catch, was not included as covariate because it was not part of the domestic fisheries in 1990. Month was used as a fixed factor because by-catch of halibut and crab species experiences temporal variations (Adlerstein, 1991).

Data were subjected to the model $Y_{ij} = \mu + \alpha_i + \beta_j + \alpha\beta_{ij} + b_{1ij}X_1 + b_{2ij}X_2$ where Y is the natural logarithm of the prohibited species by-catch rate + 1 (in kilograms of halibut or number of crabs per tonne of groundfish) for the i th month and the j th time periods, X_1 and X_2 are the proportions of Pacific cod and rock sole in the catch, and α and β are model intercept parameters for the month and time period modifying the overall mean μ . The logarithmic transformation of the by-catch data normalized the distribution of the errors. We fitted the full model and tested for differences in the model slopes between month and time of the day periods as well as for differences between the means. Applying day parameters of the model together with night catch proportions and comparing the results with estimates obtained from night parameters, we were able to estimate monthly savings of prohibited species by-catch that would be obtained if the night catches of fisheries under consideration were harvested during day hours.

Results

Comparison of the parameter estimates of the three time categories (β_i) in fitting the full by-catch model revealed that by-catch rates of halibut and the crab species in the transition category were not significantly different from the night rates (halibut: $p(|t| \geq 0.816) > 0.2$; king crab: $p(|t| \geq 1.108) > 0.2$; Tanner crab: $p(|t| \geq 0.891) > 0.2$). Thus, for further analysis we combined the transition and night categories. Observed mean by-catch of the combined data for the three prohibited species was higher during night hours (Fig. 2). Results of the ANCOVA using day and night-time categories showed that three-way interactions between Pacific cod, month and day/night periods were not significant at an α level of 0.05 ($F_{4, 1370} = 2.152$; $p = 0.072$), nor between rock sole, month and day/night periods ($F_{4, 1370} = 1.961$; $p = 0.098$). Two-way interaction between Pacific cod and month was not significant ($F_{4, 1378} = 1.846$; $p = 0.118$), nor were the interactions between rock sole and month ($F_{4, 1378} = 1.653$; $p = 0.159$), Pacific cod and day/night period ($F_{1, 1378} = 2.729$; $p = 0.099$), and rock sole and day/night period ($F_{1, 1378} = 2.575$; $p = 0.109$). These results allowed us to perform an ANCOVA (intercepts) using common slopes (b_1 and b_2) models. Results from the ANCOVA indicated that by-catch rates vary by time of the day ($p = 0.004$), by month ($p < 0.0005$), and with the proportion in the catch of Pacific cod ($p < 0.0005$) and rock sole ($p < 0.0005$). The interaction between month and time of the day was not significant ($p > 0.25$)

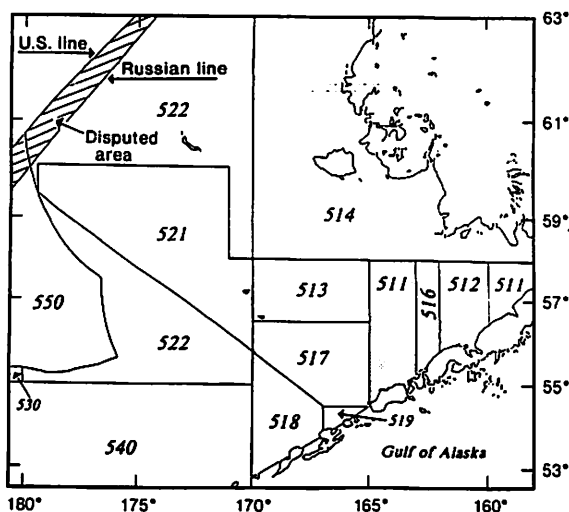


Figure 1. Regulatory areas in the Bering Sea/Alcution Islands. Data for the analysis were taken from the stippled area of Area 511.

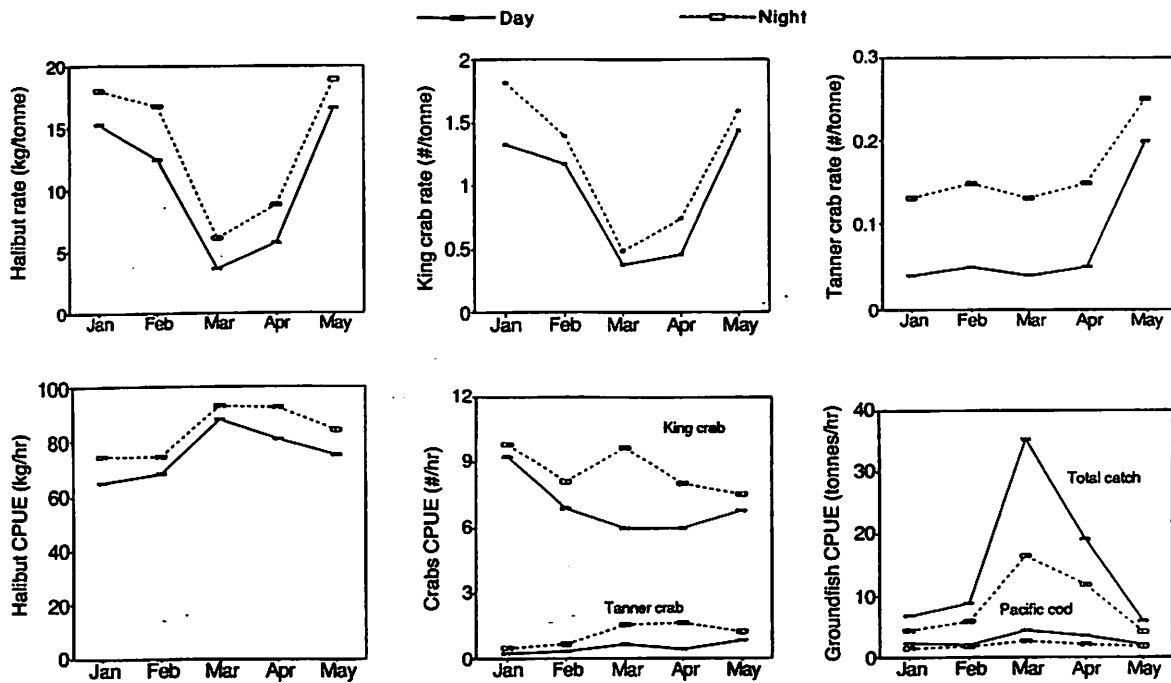


Figure 2. Observed mean by-catch rates of the prohibited species, and catch per hour of groundfish and prohibited species in Arca 511, 1990.

(Table 1). A Filliben test (Filliben, 1975) performed on the ordered model residuals indicated no evidence against assuming normal distribution of the errors (Filliben coefficient = 0.9989, $p < 0.05$).

Inspection of the parameter estimates of the common slopes model incorporating month, time of the day, and proportions of cod and rock sole, shows that the intercept of the model is increased during night hours over the day intercept (Table 1). Thus, since the slopes remain the same during the two time periods, halibut by-catch rates for a given catch species composition are higher at night than during the day. We estimated potential savings obtained by fishing during day hours by using parameters in Table 1 and catch composition. The results indicated that if night catches were taken during the day, the by-catch rates would be reduced by 16.2% in January, 16.4% in February, 17.4% in March, 35.4% in April, and 15.2% in May.

Results of the ANCOVA on the by-catch data of the two crab species showed similar results to those obtained from the halibut data. Three- and two-way interactions between the covariates and factors were non-significant ($p > 0.1$ in all cases). This allowed us to perform the ANCOVA using common slopes models. Results from the ANCOVA on the king crab data using the common slopes model revealed that day and night by-catch rates are significantly different from each other ($p < 0.0005$)

Table 1. Results of analysis of covariance of the by-catch rate (Y) of Pacific halibut for the effect of month (January to April), and time of the day (night and day) accounting for the proportion of Pacific cod (X1) and rock sole (X2). Covariates, factors, and interactions are assessed simultaneously, with each effect adjusted for all other effects in the model.

Source of variation	SS	DF	F	P
Month	178.80	4	43.525	<0.0005
Day/night	8.44	1	8.173	<0.004
Rock sole	61.37	1	61.367	<0.0005
Cod	87.02	1	87.016	<0.0005
Month, day/night	2.613	4	0.635	>0.25
Residual	1426.8	1389		

Parameter estimates for the model including significant variables $Y_{ij} = \mu + \alpha_i + \beta_j + b1X1 + b2X2$

	Estimate	s.e.	Parameter
1	1.680	0.1003	μ (January, day)
2	-0.2956	0.1017	α_2 (February, day)
3	-0.6809	0.1124	α_3 (March, day)
4	-0.3854	0.0983	α_4 (April, day)
5	0.3978	0.0911	α_5 (May, day)
6	0.1659	0.0578	β_2 (night)
7	2.047	0.2555	Rock sole (covariate) (b1)
8	1.189	0.1232	Pacific cod (covariate) (b2)

α_1 and β_1 are constrained to 0. Standard errors of the intercept α_i and β_j are of the difference between the corresponding factor levels and μ .

and that the night intercept is increased over the day intercept. All other variables were significant in determining by-catch ($p < 0.0005$). We estimated rate reductions as before. Rates could be reduced by 17.2% in January, 20.8% in February, 28.7% in March, 26.4% in April, and 19.0% in May. Results from the ANCOVA using the reduced model on the Tanner crab data indicated that day and night by-catch rates are significantly different from each other ($p < 0.005$) and that the night intercept is increased over the day intercept. We estimated rate reductions to be 31.9% in January, 34.9% in February, 37.7% in March, 34.4% in April, and 39.4% in May.

By-catch rates are determined by the relative abundance of prohibited species and groundfish in the catch. Catch per unit effort (c.p.u.e. in tonnes/h) of groundfish decreases significantly at night: $p(|t| \geq 2.724) < 0.005$ for all month (Fig. 2). In particular c.p.u.e. of Pacific cod decreases during the night: $p(|t| \geq 1.953) < 0.05$ for all months. Lower c.p.u.e. of the groundfish catch during night suggests that fish are less available or vulnerable to the net near the seabed during those hours. Lower availability is consistent with hydroacoustic observations in the Bering Sea that the two main species in the catch, Pacific cod and walleye pollock, rise off the bottom during the night (E. P. Nunnallee, pers. comm., NMFS, Seattle). Also, catch rates of cod (*Gadus morhua* L.) in bottom trawl surveys have been reported to be higher by day (Engas and Soldal, 1992). Halibut, king crab and Tanner crab, c.p.u.e.s by month are consistently higher at night (Fig. 2), although the differences between the two time periods are not significant ($p(|t| \geq 0.543) > 0.5$; $p(|t| \geq 1.528) > 0.1$; $p(|t| \geq 1.679) > 0.1$). Higher c.p.u.e. can be due to increased vulnerability or availability of prohibited species near the seabed during night hours. We observed that length frequency distributions of halibut by-catch during day and night hours show significant differences (Kolmogorov-Smirnov two-samples test p of $Z < 0.0001$). The tendency is to find higher proportions of fish larger than 50 cm in night hauls than in day hauls. It is possible that fish vulnerability changes between dark and light periods because large halibut are more likely to avoid the nets during light periods. No information was accessible to us to investigate diel changes in availability. Nevertheless, Walsh (1991) reported no evidence of changes of availability of American plaice or yellowtail flounder in relation to light intensity. The variation of the crab species, c.p.u.e. between day and night periods may be due to differences noted in behaviour between a period of diurnal rest and one of nocturnal foraging, as noted by Dew (1989) in king crabs. Nocturnal aggregations result in pods, which are accumulations of several hundred to several thousand crabs. It is conceivable that nocturnal activity may increase availability compared with the day situation when crab are resting in a hiding site.

Discussion and conclusion

By-catch rates of prohibited species in the walleye pollock and Pacific cod bottom trawl fisheries in the Bering Sea were found to be higher during the day than during night hours. Increase in halibut and crab by-catch rates at night is probably the result of the behaviour of the species involved in the bottom trawl fisheries. The relative abundance of the groundfish (mainly walleye pollock and Pacific cod) on bottom decreases during the night, seemingly because species migrate towards the surface during the night. Observations of cod migrating to midwater at night (i.e. Beamish, 1966; Turuk, 1973) support this hypothesis. However, movement in the opposite direction has also been observed. Turuk (1973) demonstrated that the direction of the migration is related to the cod diet: when feeding on actively swimming prey, cod descend during the day and ascend at night; if benthic organisms predominate in the diet the opposite is true. Although Pacific cod diet exhibits much diversity, in the study area this species feeds primarily on pelagic fish such as juvenile pollock (Brodeur and Livingston, 1988).

Prohibited species' c.p.u.e. are consistently, although not significantly, higher at night. Higher halibut c.p.u.e. in kg h^{-1} is related to higher proportion of large fish in night catches. We speculate that during the day large fish are more likely to avoid the nets. This is in agreement with the suggestion that vision is the predominant sense used in avoidance reaction when a fish is approached by a trawl (Wardle, 1986). Walsh (1991) demonstrated higher escapement of large flounders (plaice and yellowtail) under the groundgear during the day than during night hours. The night increase in crab c.p.u.e. is consistent with observations of crab podding activity. Dew (1989) reported on diel activity cycles and foraging dynamics of king crab in the general area of this study. We propose that high catch rates at night are generated by fishing when crabs are active and highly aggregated.

Irrespective of the origin of differences in by-catch rate, it is clear that savings may be obtained in the fisheries considered in this study by avoiding fishing during dark hours. Avoiding night fishing may extend the groundfish fishing seasons and increase the harvest of their allowances. From the NORPAC data and information provided by Jerry Berger (pers. comm., NMFS, Seattle), we estimated that for Area 511 the total harvest for Pacific cod and walleye fisheries and the total halibut by-catch are around 50 000 and 500 tonnes respectively. This is about 10% of the entire bottom trawl harvest and halibut by-catch of the Bering Sea. Based on the data from the 1990 fishing season in Area 511, day-only fishing can reduce total halibut by-catch by 13%. Conversely, for the same amount of by-catch taken in the area, day fishing would allow 13% more of the groundfish harvest. Day-only fishing would result in 13% sav-

ings of king crab by-catch in numbers, and 16% savings of Tanner crabs. In many instances a change in management strategies designed to protect a particular prohibited species, such as imposing fishing seasons or closing specific areas to harvest, can be to the detriment of other prohibited species. Day-only fishing in the Bering Sea of the fisheries considered, however, appears to reduce concurrently the by-catch rates of Pacific halibut, king crab, and Tanner crabs.

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