Direct observations on the hooking behavior of Pacific halibut, *Hippoglossus stenolepis*

Stephen M. Kaimmer
International Pacific Halibut Commission
P.O. Box 95009
Seattle, Washington 98145
E-mail address: stevek@iphc.washington.edu

Abstract.–Direct observation of a 6-hook model setline off Canada's northwest coast with an underwater camera allowed estimation of approach direction, attack rate, and hooking success for Pacific halibut (*Hippoglossus stenolepis*). In observations of 129 halibut approaches, 29 halibut simply continued swimming past the gear and away. The remaining 100 halibut responded in some way to the gear, exhibiting behaviors ranging from a simple change in swimming direction toward the gear, to bites on the baited hooks. Behavior transitions are described both leading up to and following 57 observed bites. Halibut displayed a positive rheotactic response; 74% approached upstream toward the bait. A higher proportion of upstream approaches resulted in bites than approaches from other directions or approaches that occurred during slack current. Most bites were associated with a vigorous rushing behavior, which often led to hooking. Hooking success was demonstrated to be length-dependent, ranging from zero for the smallest fish to approaching one for the largest sizes caught. Very low rates of hooking success were observed for some rockfish, which in some areas are important bycatch species of the halibut fishery.

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The International Pacific Halibut Commission (IPHC) sets harvest quotas for the stock of Pacific halibut (*Hippoglossus stenolepis*) off the Pacific shores of the United States and Canada. An important tool in setting these quotas is the catch per unit of effort (CPUE) both of the directed commercial fisheries of these countries and of setline surveys conducted annually by the IPHC. The trends in these CPUE indexes, both among areas and over years, are important to the IPHC stock-assessment model. Over the years, the IPHC has conducted fishing experiments in order to understand different aspects of CPUE. A selection curve for the size 16/0 J-style hooks used in the fishery prior to 1984, demonstrated by Myhre (1969), ranged from zero for fish around 40 cm, to one for fish around 80 cm. The mechanism for size selection in halibut has not been demonstrated. Skud (1978) reported that halibut was a dominant predator, probably more successful than other species in competing for setline baits, and concluded that although other fish and invertebrates, even if not caught, could cause bait loss, competition by these species was unlikely to affect the CPUE of halibut. Later studies with circle hooks (Hoag et al., 1984; Kaimmer and St-Pierre, 1993) demonstrated effective competition by a decreased catchability of halibut associated with the presence of large numbers of spiny dogfish (*Squalus acanthias*).

Attack rate (bites/fish) and hooking success (hookings/bite) by fish length are important parameters of most hook-catch models (Deriso and Parma, 1987), although these parameters often must be estimated from either a theoretical model or observations of captive fish. This paper presents results from an IPHC study designed to estimate these parameters directly from observations of halibut approaches and of bites on the circle hooks used in the present-day fishery. These behavioral studies conducted in the field, rather than through observation of captive fish, should yield results most applicable to and representative of setline catches of wild fish (Løkkeborg et al., 1993).

Materials and methods

Vessel and area

A 12-day experiment was conducted 11–20 June 1994 from a 15.5-m chartered vessel. An underwater camera permitted a view of a model setline consisting of six baited fishing hooks. The gear was placed at various halibut habitats in the Queen Charlotte Islands of British Columbia, Canada. This region was chosen to provide an opportunity to view a variety of halibut habitats, in terms of depth and bottom type, with a likelihood of relatively good water clarity. The midsummer timing allowed for the presence of halibut on their midyear feeding grounds, long working days, the opportunity of fair weather, and a window between expected plankton blooms. Camera equipment was deployed 45 times, primarily off the northern and northwestern shores of the Queen Charlotte Islands (Fig. 1). Bottom habitat ranged from mud or soft sediment, gravel, cobbles, or large boulders, to steep ledges. Deployments were intended to last about one hour. Problems with strong currents or the loss of four or more baits due to fish captures or other reasons resulted in early gear retrievals. Longer deployments resulted from gear retrieval problems. Time on bottom for each deployment averaged 58 min (range 14–150 min, SD 28 min). Average depth for all sets was 67 m (range 11–84 m).

Equipment

A silicone-intensified tube (SIT) monochrome video camera (model OE1323, Osprey Electronics Ltd., Aberdeen, Scotland) was housed in an enclosure featuring both pan and tilt functions. This enclosure was mounted in an aluminum cage connected by 5-cm aluminum pipe to a square base frame constructed of 5-cm steel pipe (Fig. 2). The camera–frame assembly was deployed by, and monitored through, an electromechanical cable. All observations were made by using ambient available light.

A 0.8-cm (5/16-inch) diameter groundline was suspended about 30 cm inside the base frame by short lengths of elastic cord attached to the inside corners of the steel frame. This arrangement resulted in an elastic attachment for the hooks and gangions. This "soft" attachment was probably a more realistic model of the behavior of a gangion on a groundline than an attachment made directly to the rigid steel frame. The study used 16/0 circle hooks (O. Mustad and Sons, Oslo, Norway, Quality 39965), the size and style most commonly used in the Pacific halibut fishery, and the standard in IPHC surveys. Hooks were attached by 81-cm (32-inch) gangions and snaps to the suspended groundline, one per side alternating with two per adjacent side, for a total of six hooks. All hooks were baited with 0.17-kg (1/3-lb) pieces of chum salmon (*Oncorhynchus keta*) fillet with skin intact.

Observation of a 25-cm length of flexible surveyor's tape attached to one of the aluminum legs, as well as of dust or sediment plumes during bait attacks, was used to determine the direction of bottom current and also as a qualitative measure of current strength. The video signal was monitored and recorded at all times. When viewed directly from above, all parts of the square base were within the field of view. This usually meant that all six hooks could be viewed at the same time. When one or more hooks lay outside the base frame, the camera was periodically redirected for viewing these outside hooks.

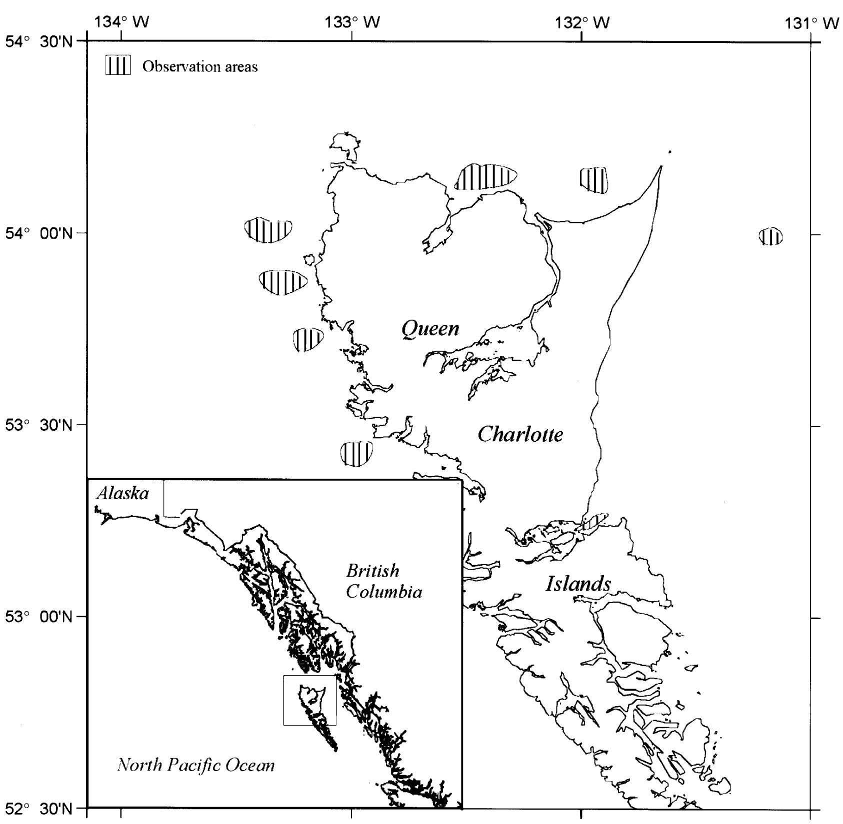

Figure 1

Location of camera deployments. Box in inset shows general area of operation.

Fish length and distance measurements

Lengths of 20 hooked and landed halibut were measured. During video editing, relative fork lengths for all halibut that could be clearly viewed on or near the bottom and at or near the center of the frame were obtained by using a vernier caliper held against the video screen while the video image was frozen. The linear regression between measured and relative fork length (r= 0.74) was used to estimate the fork lengths of 92 fish not captured and retrieved, as well as the distance from fish lying on the bottom to the nearest baited hooks. Caught fish, other than halibut, were weighed to the nearest 0.5 kg on a spring scale.

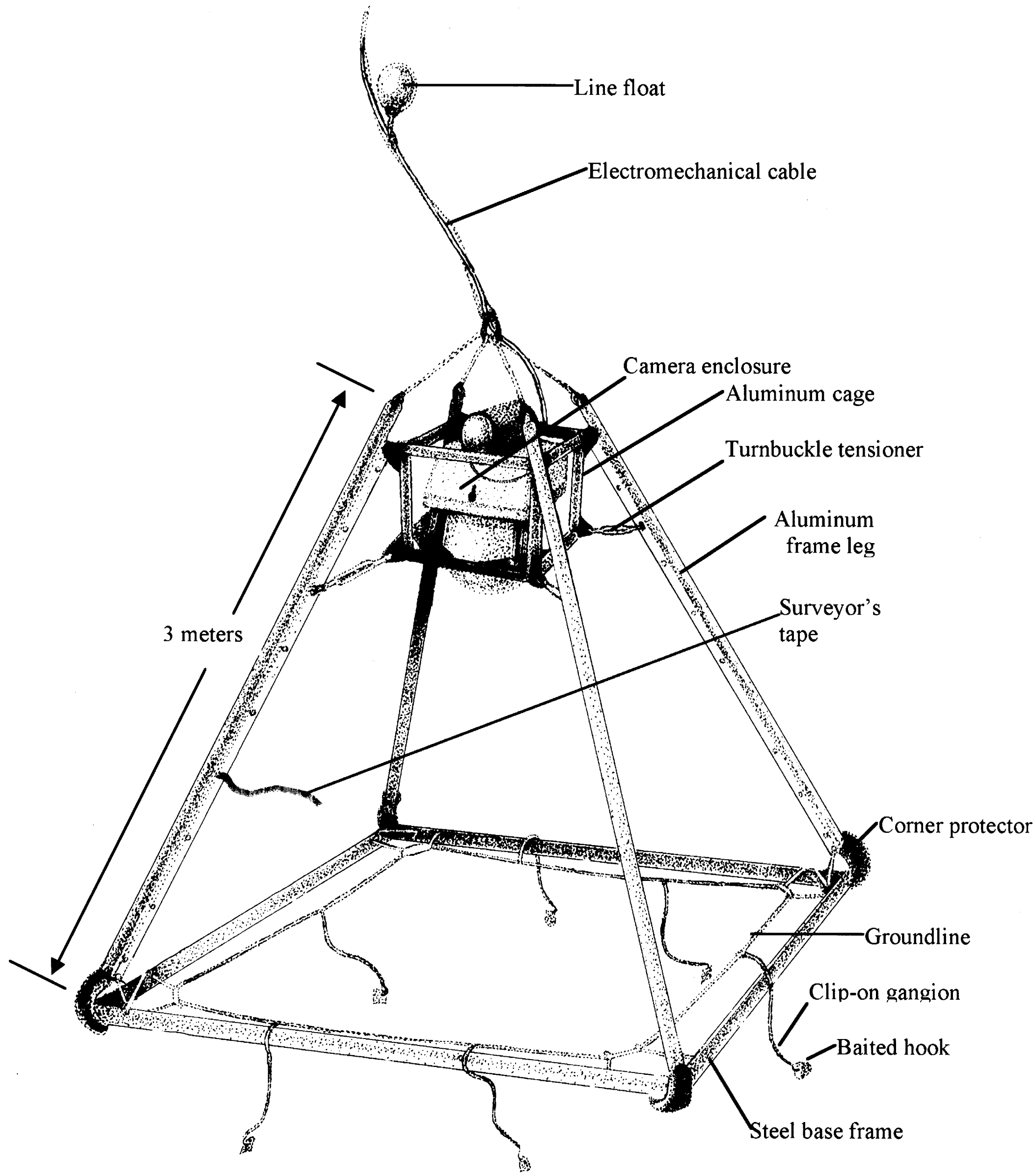

Figure 2
Camera cage and frame, showing attachment of groundline and baited hooks.

Observations of behavior

Appearance and subsequent behavior sequences were recorded for all halibut, including the directions of both appearance and departure in relation to the bottom current. All behaviors were coded as to time at which the behavior either occurred or was initiated, to the nearest second. Behavior codes were modified from those used by Fernö et al. (1986). For species other than halibut, only bites and hookings were recorded. Unless otherwise specified, code descriptions and frequencies refer to halibut only.

Behavior definitions

The word "observed" was recorded upon the first appearance of a halibut, along with its approach direction in relation to the bottom current, and a number was assigned to the fish in order to identify future observations on that fish.

The word "looping" was recorded when a swimming fish made a turn of more than 90 degrees.

"Lying" was recorded when a fish stopped swimming and lay on the bottom, and included (for fish that lay near hooks) direction to the closest baited hook in relation to bottom current.

"Biting" was recorded when a fish took a baited hook completely into its mouth.

An "incomplete biting" was recorded when a fish touched a bait but the bait or hook was never completely within its mouth.

"Grazing" was recorded if a fish bit at a piece of bait that was not attached to a hook. Pieces of bait would occasionally fall free from the hook during the rushing following a bite.

"Rushing" was recorded when a fish swam rapidly forward with the bait or hook in its mouth.

"Spitting" was recorded when bait was either spat or pulled out of a fish's mouth.

"Hooking" was recorded when a fish retained a hook in its mouth for at least twenty seconds, usually while the fish struggled or fought violently. This time period was chosen as consistent with that in other literature on hooking behavior (Fernö et al., 1986; Huse and Fernö, 1990). However, hooking was not recorded until completion of the rushing behavior. When biting was followed by rushing lasting more than twenty seconds, which was in turn followed by spitting, that portion of the behavior sequence was listed as "biting, rushing, spitting." A fish that rested after rushing with the hook still in its mouth, and which subsequently after twenty seconds or more rushed and spat out the hook, was listed as "biting, rushing, hooking, lying, rushing, spitting."

"Attacking" was recorded when a fish chased or bit at another fish, either a halibut or one of the other species in the viewing area.

"Departure" was recorded, along with direction of travel in relation to bottom current, when a fish left the observation area. Occasionally, a fish would leave the observation area and be identified on its subsequent return by a short duration of absence (less than 5 s), and by its length, and body markings. In these cases, the period of nonobservation was recorded as "looping."

Sequential occurrences of either lying or looping were coded as single occurrences. Consecutive lying behaviors were coded as a single behavior occurrence only when the subsequent lying was the result of a small position shift and the fish did not shift to a different bait. Twenty-one occurrences of behaviors were considered compromised by the experimental setup. A behavior transition beginning with a compromised behavior was considered invalid. For example, a bite where the hook or gangion was wrapped around the frame was considered compromised, and the transition to the following behavior was considered invalid.

Direction in relation to bottom current

Fish approaching or departing within 67.5° to either side of and into the current were coded as "upstream." Fish swimming within the next 45° on either side of the current (within a 22.5° arc to a line perpendicular to the current) were coded as "right angle to the current." Fish swimming within 67.5° to either side of and out from the current were coded as "downstream." These same criteria were used to record the direction in which a fish was lying in relation to a bait.

Results

The number of halibut observed was 129, ranging from none (on 19 sets) to a high of 19 (on one set). On average, 5.6 halibut were observed on sets where at least one halibut was seen, and the numbers of halibut caught per set ranged from 0 to 4. Measured fish ranged from 72 to 114 cm in length (mean=86.8 cm, SD=11.4 cm). Calculated lengths ranged from 52 to 196 cm (mean=90.1 cm, SD=24.2 cm).

Behaviors and behavioral transitions

The time until first appearance of the first halibut in a set varied widely, ranging from almost immediately (18 s) to more than an hour after the gear was set (1 h 1 min), and averaged 18 minutes (SD=13 min 32 s). For 29 fish that swam away immediately after observation, the time between appearance and departure ranged from 7 to 33 seconds (mean=9 s, SD=7 s). Orientation in relation to bottom current was noted for 93 halibut approaches (Fig. 3). Another 18 approaches were noted as occurring during slack current. Of those fish that approached during periods of noticeable current, 75% approached upstream, 9% approached at right angles to the current, and 17% approached downstream.

Looping and lying were the most common behaviors, with 80 loopings recorded for 60 halibut and 70 lyings recorded for 45 halibut (Table 1). The average durations of looping and lying behaviors were 40 and 14 seconds, respectively (Table 2). Fifty-seven bites were observed; 48 halibut made a single bite, 3 halibut made 2 bites, and 1 halibut made 3 bites. A total of 25 halibut were classed as hooked. The transition matrix in Table 3 details 426 valid behavior transitions constructed from the observations. The main function of the matrix was to show possible patterns or combinations of behaviors that occurred more or less frequently than expected if all possible behavior transitions had the same probability of occurring. Statistical analysis of this matrix is complicated by the fact that not all transitions were possible (a spitting may only follow after biting or rushing). The matrix was therefore visually inspected for large differences, as recommended by Slater (1973).

Prebiting behavior and attack rate

There were 293 transitions observed for halibut, not including behaviors that followed initial complete bitings. The number of prebiting transitions per individual fish ranged from one to fifteen, with 78% of the fish making three or less transitions, and over 90% making five or less.

Looping and lying near bait were the most common behaviors following initial observation. Less commonly observed were departures, biting, and incomplete biting. Looping behavior was followed about equally by lying near bait, biting, and departure. Lying near bait was most often followed by either looping or biting, and less often by departure or an incomplete biting. For 71 occurrences of lying behavior, 8 either had no obvious hook orientation or occurred during slack current, 3 fish lay upstream of bait, 26 lay to the side of bait, and 34 lay downstream from bait. The distance from bait for fish lying beside or downcurrent averaged 13.2 cm (SD=8.4 cm) and 14.6 cm (SD=9.0 cm), respectively. Incomplete biting was most often followed by lying near bait, and less often by departing or looping.

The transitions in Table 3 do not consider preceding behaviors, or how many previous behaviors a particular fish had completed. As each of the original 129 halibut was observed through the first four behavior transitions up to either biting or departing, there was a tendency for fish to stay in interaction with baits. Lying, incomplete and complete biting, and grazing are all behaviors that are direct interactions with either the bait or food present around a baited hook. In the first transition (n=129), fish were most likely to interact with bait (43%), loop (34%), or depart (23%). About one-third of the bait interactions in the first transition were bites. In the second transition (n=78), fish were most likely to interact with the bait (57%) or depart (40%). Only 12% looped. Again, about one-third of the bait interactions were bites. By the third transition (n=28), fish were much more likely to continue bait interactions (68%) than they were to loop (25%) or depart (7%). About one-quarter of bait interactions were bitings.

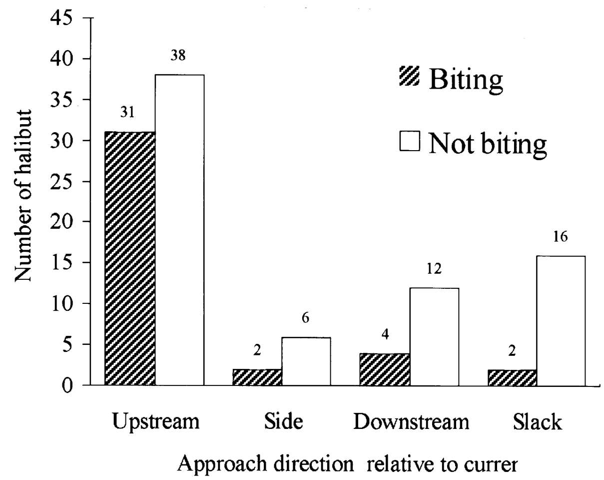

Figure 3

Numbers of halibut biting and not biting, by approach direction in relation to bottom current.

Table 1

Frequencies of halibut behaviors observed. Individual fish may be counted as performing more than one behavior.

Behavior	Count	Number of individual fish
Appearance	129	
Looping	80	60
Lying	70	45
Incomplete biting	15	9
Biting	57	52
Rushing	53	48
Hooking	25	25
Spitting	30	27
Grazing	4	3
Attacking	3	3
Departure	96	—
Grand total	562	

In the fourth transition (n=21), 62% continued with bait interactions, almost half of which were bitings, 21% departures, and 19% loopings. By the end of the fourth behavior transition, out of the original 129 halibut observed, approximately half (66 fish) had departed, whereas just over a third (47) had made complete bites. In each of the transition levels, 43–68% of behaviors were directed toward baits.

Elapsed time between appearance and the first observed bite for all halibut ranged from 1 s to 7 min 54 s (mean=34 s, SD=1 min 5 s). Ninety-five percent of first bites occurred in less than 1 min 20 s after first appearance, and 50% occurred within the first 20 s. Although no significant difference was noted between time to first bite and approach direction, for the 36 observations where the approach was made during some current, the maximum time to first bite was 2 min 51 s. Of two bites following appearances during slack current, one bite occurred almost 8 min

Table 2

Duration of observed halibut behaviors.

Behavior	No. of observations	Duration Range	Duration Average (±SD)
Prior to hooking			
Looping	80	3 s–6 min 32 s	40 s (±62 s)
Lying (prior to hooking)	70	1–68 s	14 s (±15 s)
Rushing (followed by spitting)	31	1–63 s	10 s (±13 s)
Rushing (followed by hooking)	22	24 s–3 min 30 s	86 s (±44 s)
Following hooking			
Lying	34	3 s–22 min 8 s	3 min 49 s (±5 min 19 s)
Rushing	24	8–78 s	31 s (±19 s)

Table 3

Transition matrix of observed values (upper number) and expected values (in parentheses) for the frequency of transitions from one behavior to another within behavior sequences. Top row is the first behavior in a transition and the leftmost column is the second behavior. For example, a fish that was observed, made one loop, and then swam away would have two tallies in this table, one for "appearance" followed by "looping," and a second for "looping" followed by "departure." Behavior transitions starting with compromised behaviors are not included in this table.

Second behavior	First behavior: Appearance	Looping	Lying	Incomplete biting	Grazing	Biting	Rushing	Spitting	Attacking	Total
Departure	29 (38.0)	30 (28.7)	12 (25.3)	3 (3.8)	— (0.9)	—	—	20 (8.8)	— (0.6)	94
Looping	44 (31.1)	—	21 (20.7)	2 (3.1)	— (0.7)	—	—	9 (7.2)	1 (0.5)	77
Lying	32 (28.3)	27 (21.4)	—	8 (2.8)	2 (0.7)	—	—	— (6.6)	1 (0.4)	70
Incomplete biting	4 (6.1)	1 (4.6)	10 (4.0)	— (0.6)	— (0.1)	—	—	— (1.4)	— (0.1)	15
Grazing	— (1.6)	1 (1.2)	3 (1.1)	— (0.2)	— (0.0)	—	—	— (0.4)	— (0.0)	4
Biting	19 (23.1)	15 (17.4)	21 (15.3)	1 (2.3)	— (0.5)	—	—	1 (5.4)	— (0.4)	57
Rushing	—	—	—	1 (2.1)	—	52 (27.2)	—	—	—	53
Spitting	—	—	—	—	—	2 (14.9)	27 (27.4)	—	—	29
Hooking	—	—	—	—	—	1 (12.9)	24 (23.6)	—	—	25
Attacking	1 (0.8)	— (0.6)	— (0.5)	— (0.1)	1 (0.0)	—	—	— (0.2)	— (0.0)	2
Total	129	74	67	15	3	55	51	30	2	426

after initial appearance, more than twice the longest elapsed time between appearance and first bite for fish that appeared when bottom current was noticeable.

There were differences in the biting behavior of halibut associated with their direction of approach in relation to bottom current (Fig. 3). The difference was significant (upstream 45%, side or downstream 25%; χ^2=33.1, P<0.0125), as was the difference between fish that approached when current was or was not noticeable (current 49%, no current 11%; χ^2=5.4, P<0.0125). Overall, attack rate (bites/fish) was 33–73% over the range of lengths observed (Table 4). Although approach direction in relation to current had a significant effect on attack rate, there was no relation between fish length and attack rate for 41 halibut that had approached upstream. For these fish, the attack rate for fish less than 82 cm (sublegal size) was 46% (11 of 24), and the rate for fish 82 cm or larger (legal size) was 47% (8 of 17).

Direction in relation to the current was noted for 54 departures. Thirty-three (61%) halibut departed upstream, 6 (11%) departed at right angles to the current, and 15 (26%) departed downstream.

Postbiting behavior and hooking success

Almost all bites (95%) occurred while fish were in motion: a fish swam toward the bait, took the bait in its mouth, and continued swimming (rushing). In two cases, a lying fish took bait and subsequently spat it out without rushing. In one case, a lying fish kept the bait in its mouth long enough (20 s) to be classified as hooked, but without rushing.

Rushing behavior was about equally followed in frequency by either spitting the hook (53%) or hooking (47%). On average, spitting occurred 10 s after the start of rushing behavior; rushing that did not result in spitting had an average duration of 86 s (Table 2). In two-thirds of the cases where the hook was spat, the fish departed rapidly. Thirty percent of spittings were followed by looping behavior and, in one case, the fish immediately rebit the hook. One "steal" was observed, where the fish swam free from the hook with the entire bait in its mouth. Hooking success (hookings/bite) by 5-cm length group was 0–83% and increased steadily with increasing fish size. The difference in hooking success between fish of sublegal (<82 cm) and legal (≥82 cm) length was highly significant (38% vs. 71%; χ^2=4.36, df=1, P<0.025).

Figure 4 shows observed postbiting behavior transitions, from an initial complete bite by an individual fish through the fourth behavioral transition. Of 50 fish tracked on this chart, 20 ended up departing, 22 ended up hooked, and 3 were still interacting with hooks at the end of the fourth behavioral transition. Of the three continuing interactions, one fish lay near bait and two fish rebit baited hooks. Fifty percent of

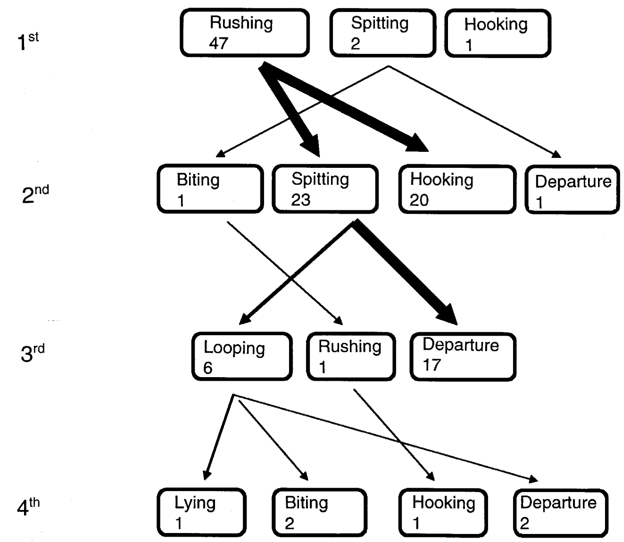

Figure 4

Behavior tree describing behavior sequences following an initial complete bite. Numbers at left of rows are the position of behaviors in sequences following initial observation. Numbers in boxes are the total frequencies of each behavior in a row position. Thickness of arrows represents relative numbers of observations for each behavior transition. Because some behaviors were compromised, not all behaviors have transitions from one row position to the next.

Table 4

Halibut attack rate (% of fish biting) and hooking success (% of bites resulting in hooked fish) by 5-cm group.

Size class (cm)	Number observed	Number of bites	% bites	Number hooked	% hooked
62–67	6	3	50	0	0
68–72	11	5	45	1	20
73–77	17	9[1]	53	3	38
78–82	11	8	73	5	63
83–87	12	5	42	3	60
88–92	18	6	33	4	67
93–97	12	6	50	5	83
Total	87	42		21	

[1] One bite in the 73–77 cm size class was compromised. Percentage hooked is determined from the eight uncompromised bites.

spits occurred in less than 5 seconds, and 95% occurred in less than 25 seconds. Once hooked, and after initial rushing, the halibut lay on the bottom, resting, then went into a pattern of rushing, resting, rushing, etc. There appeared to be a pattern of decreasing duration of rushing following subsequent rest periods. The average times for resting and rushing after the initial hooking were 3 min 49 s, and 31 s, respectively (Table 2).

Hooking success for other species

The range of approach and interaction behaviors for species other than halibut was not documented beyond noting bitings and subsequent hooking. Other species that bit at hooks included canary rockfish (*Sebastes pinniger*), yelloweye rockfish (*S. ruberrimus*), quillback rockfish (*S. maliger*), ratfish (*Hydrolagus colliei*), and lingcod (*Ophiodon elongatus*). In general, hooking success for the major rockfish species was around 5–6% (Table 5). These fish were comparable in average size (weight) to those caught as incidental catch in the directed halibut fishery.

Discussion

The feeding behavior of halibut may be classified into three phases: arousal, search, and bait attack and food ingestion.

Arousal

In most cases, arousal to the presence of food occurs at a distance, and bait odor carried by bottom currents attracts fish from well beyond the limited viewing distance of the present experiment. Although undoubtedly involving detection of an odor plume (Atema, 1980), the present experiment did not investigate the initial arousal phase of feeding behavior. However, a number of observations in relation to food location and uptake were made.

Table 5

Hooking success for species other than halibut.

Species	Number of bites	Number hooked	% hooked	Average weight (kg) of hooked fish
Canary rockfish	339	17	5	4.0
Yelloweye rockfish	237	20	8	3.8
Quillback rockfish	228	9	4	1.9
Ratfish	36	1	3	N/A
Lingcod	23	9	39	11.1

Search

It is clear that halibut use orientation to bottom current to locate food, most approaching upstream when a bottom current was present. This rheotactic orientation is used by many fish for detection and location of prey (Atema, 1980; Løkkeborg et al., 1989; Løkkeborg, 1998). Once fish are aroused to the presence of a prey item by scent, they orient into a current to locate the food.

The role of vision in food location by Pacific halibut was less clear. Behaviors directed towards the gear were observed in some cases immediately after the gear reached the seafloor. These were likely responses to visual clues. However, the greatest number of appearances appeared to be motivated by scent carried by the current. Although earlier studies have shown that halibut certainly prey on a number of pelagic or semipelagic species where vision must play an important role in prey recognition and capture (Best and St-Pierre, 1986), it probably played a limited role in behavior toward the model setline.

Prebiting behavior and attack rate

Fish vary widely in their reliance on sight, smell, and touch in deciding whether to accept or reject food once it has been located (Løkkeborg, 1994). Both looping and lying behaviors were common in the observed halibut, and in only a few cases was a complete bite initiated without some preliminary bait interaction such as looping or lying. Looping behavior could be a test of an odor plume by the fish, assuring that the fish is in an area of high-scent concentration. Many halibut lay near the bait prior to initiating a bait attack, most either directly downstream or to one side of the bait in relation to the current. This behavioral response may reinforce olfactory clues that led the fish to the bait, or possibly a restrained response to the baited hook as a novel prey item (Løkkeborg, 1990). Rejection of the bait at this point was often followed by looping, behavior that often led to further bait interaction. The role of mechanoreception was not demonstrated. In only a few instances did halibut exhibit incomplete bites, and these generally did not result in the fish then leaving the area of the gear. Most bites were associated with extremely active behavior, e.g. a fish beginning to rush simultaneously with biting the bait. Only one bite that resulted in hooking was not followed by a rush.

In the simplest interpretation, the attack rate for halibut was 43%. Fish length was not a significant factor in attack rate, although approach direction was highly significant; fish that approached the bait upstream bit almost twice as often as fish that approached from the side or downstream, and four times as often as fish that approached during slack current. It is likely that fish approaching upstream were following a scent trail from the baits and had a higher motivation to bite than fish that approached from other directions.

It is interesting to note that although halibut appeared throughout the gear deployment, consistent with the idea of being aroused by and following a scent plume from different distances, once a fish arrived at the area of the baited hooks, bait attacks occurred quickly. Most attacks occurred within the first minute after a halibut appeared, and less than five percent of the bait attacks occurred more than one and one-half minutes after the fish appeared.

Postbiting behavior and hooking success

In almost all cases, complete bites were followed by rushing behavior, which resulted in about equal numbers of hooked fish and fishes that spat the hook and then departed the observation area. Hooked fish struggled violently for a short period, then went into a series of resting and rushing behaviors which continued through the observation period, the duration of rushes becoming gradually shorter.

Size selectivity by hook-and-line gear has a number of components, including encounter rate, attack rate, and hooking success. A higher encounter rate has been shown for larger fish, which may have greater foraging ranges and therefore a higher probability of encountering baited gear (Løkkeborg and Bjordal, 1992; Engås and Løkkeborg, 1994; Bjordal and Løkkeborg, 1996). It is possible that the present experimental arrangement was skewed in this way toward catching larger halibut. Attack rate has been related to bait size for some species; larger fish show a preference, and therefore a higher attack rate, for larger baits, and smaller fish showing a preference for smaller baits (Bjordal and Løkkeborg, 1996). No difference in attack rate by fish size was seen in the present study.

Hooking success was found to be strongly dependent on fish length, ranging from zero for fish less than 62 cm, to 83% for fish 93–97 cm (Fig. 5). This finding is consistent with and can explain much of the selectivity estimated from representative IPHC commercial and setline survey data (Clark[1]). A circle hook is designed so that it is pulled to the corner of the mouth during rushing, with the point of the barb in line with the pull of the gangion (Bjordal and Løkkeborg, 1996). Hooking results from the orientation of the hook during the rush and the penetration of the barb caused by the pull on the gangion during that rush, the point of the hook circling the jawbone and exiting through the cheek (Johannes, 1981). Ninety to ninety-five percent of halibut caught on circle hooks are hooked in this manner (Kaimmer and Trumble, 1997).

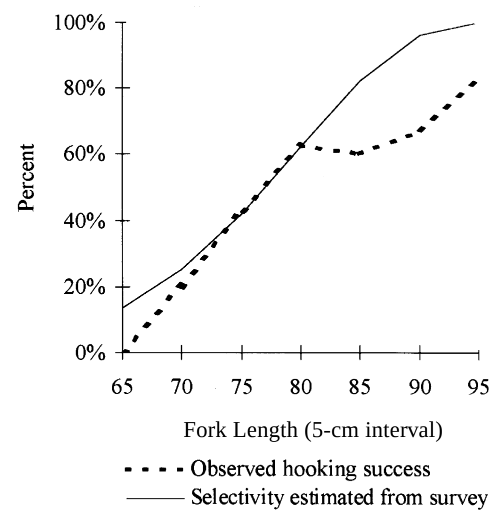

Figure 5

Hooking success from direct observation and selectivity estimated from IPHC survey data by 5-cm length groups.

Hooking success has been related to hook size only when the range of hook sizes is very great, on the order of 200% or more (Løkkeborg and Bjordal, 1992) and has been explained in terms of larger fish being able to exert a stronger pull on the gangion during rushing. This stronger pull generates the greater force necessary to pull the point of a larger hook fully into the tissue of the mouth cavity, resulting in a higher rate of hooking success. A greater hooking success as the result of a larger fish exerting a stronger pull may be countered by weaker tissue in the mouth of smaller fish, requiring less force for the hook to penetrate (Bjordal and Løkkeborg, 1996). The hooking success table (Table 4) in this study was constructed for fish 62–97 cm in length, the largest just 1.5 times the length of the smallest, and showed dramatic differences in hooking success over length changes as small as 10–20 cm. Some mechanism beyond pull strength was probably responsible for these differences. In an earlier study where the same hooks

[1] Clark, W. 1997. Coastwide distribution of exploitable biomass according to 1997 setline surveys. Int. Pac. Halibut Comm. Rep. of Assessment and Research Activities, p. 161–202. International Pacific Halibut Commission, P.O. Box 95009, Seattle, WA 98105-2009. Unpubl. manuscript.

(Kaimmer, 1994) were used, halibut less than 82 cm in length were hooked more often in locations other than the jaw than were larger halibut. Although this difference was small, it suggests a functional relation between the mechanical operation of the hook and the size of the fish's mouth in relation to overall hook and bait dimensions. A higher rate of hooking success for smaller halibut might have been seen if smaller bait had been used. This was not tested in the present experiment because bait size was held constant to the standard used in IPHC setline surveys and representative of the commercial halibut fishery.

It is clear that an increased hooking success for larger fish has a dramatic effect on the size selection of longline gear. Much of the length-based selectivity assumed for halibut setlines can be explained by the differences in hooking success by fish length demonstrated by this study. The selection curve generated from the present observations is the first to be determined for Pacific halibut through direct observation of hook attacks.

Conclusions

We consider the results of this study to be qualitative, not quantitative. Their application to commercial or experimental longline sets or CPUE indices should take into account the limited nature of the experiment, both in terms of number of hooks fished and in terms of lack of seasonal or wide areal variation in the observations. Although it is likely that the results are generally applicable to halibut, they could vary significantly for fish with different feeding histories in a different life stage. Attack rate particularly could be susceptible to the condition of fish in relation to recent feeding or spawning activity. The primary objective of this project was to determine estimates for the attack rate and hooking success of Pacific halibut on gear typical of those used in the commercial fishery. Results show that although these parameters may be estimated, their values are influenced by a number of factors, most notably by the presence of bottom current and direction of approach in relation to that current (for attack rate) and fish length (for hooking success). The behavioral sequences observed for Pacific halibut were fairly limited and included searching into a current for food, looping and lying around or near bait items, and a vigorous biting–rushing sequence that often resulted in hooking. The relative absence of physical contact with the bait prior to biting (such as tasting) might indicate that texture is less important for food selection by halibut. The role of vision in halibut feeding was not tested.

The large number of bait attacks by species other than halibut compensated for the very low hooking success for these species. In fact, we caught more of these species than halibut during the experiment. Although their presence or interaction with baits short of hooking did not seem to affect the attack rate of halibut that were present, the removal of available baits by interspecies competition should be included in any model of hook-and-line CPUE.

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