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Most fishes exhibit differences in activity patterns from day to night, with a switch from high to low activity at dusk and reverse at dawn. Marine reef fishes show similar behavior among sites, despite dissimilar species assemblages, suggesting that common selection pressures are leading to convergent behavior. Few studies to date have examined 24-hour changes in species composition and activity patterns in temperate deepwater habitats, where day to night differences in light intensity are low. In 2000, a consortium of research organizations conducted overlapping surveys during day, night, dawn, and dusk periods using the ROPOS remotely operated vehicle (ROV) on Heceta Bank, Oregon. Activity in fishes was classified by movement and contact with the seafloor. Most taxa were broadly distributed by depth, station and habitat during both day and night. General patterns in activity were similar to other shallow temperate diel studies with an overall increase in abundance and activity of fishes during the day compared to night, particularly in shallow areas of large substratum. However, few taxa showed evidence of diel niche partitioning of habitat and most taxa did not exhibit distinct diurnal or nocturnal behavior. During dawn, some taxa showed sequential emergence and increased activity over a 2.5 hour time period, although no distinct quiet period was shown. For some fishes with significant day-night differences in abundance and activity, this work suggests that daytime groundfish trawl surveys may have an important sampling bias. This research is unique in that ROV technology is used to examine diel fluctuations in abundance and activity of demersal fishes at a relatively deep, temperate rocky bank along the outer continental shelf in the vicinity of one of the most important areas for groundfish fisheries off the Oregon coast.

Diel Activity Patterns in Demersal Fishes on Heceta Bank, Oregon

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CONTRIBUTION OF AUTHORS

Julia Clemons[1] assisted by helping to conduct the survey, collect the data, process the data, and assisted in all other aspects of the diel component of this project.

Dr. W. Waldo Wakefield[1] was a primary investigator for the Heceta Bank project directly contributing to the design of the project, acquisition of funding, ROPOS ROV the survey, collection of the data, and assisted in all other aspects of the diel component of this project.

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Mary Yoklavich[3] was a primary investigator for the Heceta Bank project directly contributing to the design of the project, acquisition of funding, ROPOS ROV the survey, collection of the data, and assisted in video data review for the diel component of this project.

Dr. Brian Tissot[4] was an investigator for the Heceta Bank project directly contributing to the design of the project, acquisition of funding, ROPOS ROV the survey, collection of the data, and assisted in the review of the analysis for the diel component of this project.

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GENERAL INTRODUCTION

The rising and setting of the sun imposes constraints on the activity of most marine fishes. As a result, convergent behavioral patterns have developed that transcend geographic boundaries (Helfman, 1978). The majority of fishes exhibit higher activity during major portions of the diel cycle (either day, night, or twilight). While some fishes at low latitudes show no peak in activity, some high latitude fishes are continually active during summer, and some species exhibit timing differences in northern and southern areas of their range (Helfman, 1978). Few researchers have performed *in situ* studies to see if marine fishes exhibit reduced or more variable diel activity patterns in areas of low light intensity (Shapiro and Hepburn, 1976).

Using survey video taken on a relatively deep, rocky bank, I investigated patterns in distribution, abundance, and activity of fish taxa to see if they exhibited behaviors commonly found on shallow temperate rocky banks and tropical reefs (Hixon and Tissot, 1992; Hobson et al., 1981; Hobson, 1965, 1972; Ebeling and Bray, 1976; Moulton, 1977). The majority of diel studies of temperate fishes have only taken place in shallow (<70 m) areas (Ebeling and Bray, 1976; Hixon and Tissot, 1992; Hobson and Chess, 1976; Hobson et al., 1981; Moulton, 1977). In the first chapter of this thesis, I identify which fishes exhibit differences in activity, distribution, or abundance between day and night among different habitat types and depths. In chapter 2, I quantify changes in the activity level of fishes during dawn and dusk. In light of the current West Coast groundfish crisis (Bloeser, 1999), this work is important as it will contribute to the knowledge of diel abundance patterns and activity of several commercially important fishes off the Oregon Coast, thereby aiding the development of survey methods.

REFERENCES

Bloeser, J. A.
1999. Diminishing returns: the status of west cost rockfish, Pacific Marine Conservation Council, Astoria, OR, U.S.A., 94pp.

Ebeling, A. W., and R. N. Bray
1976. Day versus night activity of reef fishes in a kelp forest off Santa Barbara, California. Fish. Bull. 74(4):703-717.

Helfman, G. S.
1978. Patterns of community structure in fishes: summary and overview. Env. Biol. Fish. 3:129-48.

Hixon, M. A., and B. N. Tissot.
1992. Fish assemblages of rocky banks of the Pacific Northwest [Stonewall Bank]. OCS Study MMS 92-0025, USDI Minerals Management Service, OCS Study, Camarillo, CA

Hobson, E. S.
1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California, Copiea 1965:291-302

Hobson, E. S.
1972. Activity of Hawaiian reef fishes during the evening and morning transition between daylight and darkness. Fish. Bull. 70(3):715-740.

Hobson, E. S, and J. R. Chess.
1976. Trophic interactions among fishes and zooplankters nearshore at Santa Catalina Island. Cal. Fish. Bull. 4(3):567-598.

Hobson, E. S., W.N. McFarland, and J. R. Chess.
1981. Crepuscular and nocturnal activities of California nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. Fish. Bull. 79:1-30.

Moulton, L. L.
1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Ph.D. Dissertation. University of Washington, Seattle, WA.

Shapiro, C. M., and H. R. Hepburn.
1976. Sleep in a schooling fish, *Tilapia mossambica*, Physiol. Behav., 16:613-615.

Day and night activity patterns in demersal fishes on Heceta Bank, Oregon

Ted Hart

ABSTRACT

Most shallow-dwelling tropical marine fishes exhibit differences in activity patterns from day to night, showing similar behavior among sites despite dissimilar species assemblages. However, few studies have examined diel changes in species composition and activity patterns in temperate deepwater habitats, where day to night differences in light intensity are extremely low. In 2000, an interdisciplinary study of a deep-water rocky ban off the northwest coast of the United States resulted in the collection of overlapping *in situ* surveys of fishes during day and night periods. The direct-observation surveys were conducted on the largest rocky bank off Oregon, Heceta Bank, using a remotely operated vehicle (ROV). General patterns were similar to shallow temperate diel studies, with an overall increase in the abundance and activity of fishes during the day versus night, particularly in shallow areas of cobble, boulder and rock ridge. However, few taxa showed evidence of diel niche partitioning of habitat and most taxa did not exhibit distinct diurnal or nocturnal activity patterns. This analysis suggests that daytime groundfish trawl surveys may have an important sampling bias for a few fishes with significant day-night differences in abundance and activity. Our analysis is unique for its use of ROV technology to examine diel fluctuations in abundance and activity of demersal fishes at a relatively deep, temperate rocky bank in the vicinity of one of the most important areas for groundfish fisheries along the U.S. west coast.

INTRODUCTION

Similar day and night patterns in activity of fishes have been shown on shallow temperate rocky banks and tropical reefs (Ebeling and Bray, 1976; Hobson, 1965, 1972; Hobson and Chess, 1976; Moulton, 1977). Generally, two-thirds of fishes are diurnal while one-third are nocturnal, with a marked change in the vertical distribution of fishes between day and night in many species (Helfman, 1978). Within tropical and temperate fish communities, visually-oriented fishes that feed during the day are less suited to feed at night and are thus less active at that time, while nocturnal foraging fishes are less suited to feed and are less active during the day (Ebeling and Bray, 1976; Hobson and Chess, 1976; Hobson, 1972, 1974). In most species of fishes, larger-size individuals tend to be found at greater depths and are often nocturnal feeders while juveniles of the same species use shallow portions of substrata and forage during the day (Hobson and Chess, 1976; Love et al., 1991). In addition, species showing similar behavior exhibit common morphology features; nocturnal species tend to be less derived in form than diurnal taxa, and species active during twilight are commonly larger piscivores with relatively large eyes (Brouder and Pearcy, 1984; Ebeling and Bray, 1976; Hobson, 1965, 1972; Hobson and Chess, 1976; Hobson et al., 1981; Love et al., 1991; Moulton, 1977).

Day-night activity patterns within species are generally quite distinct in shallow tropical reefs (Helfman, 1978). Most fishes rigidly follow a diurnal or nocturnal activity pattern, exhibiting very low activity in shelter locations and high activity during feeding. Several Hawaiian reef fishes exhibit high site fidelity, returning to the same nighttime resting spot which is often a crevice or rocky area (Hobson, 1972). Nocturnal species are typically predators, while diurnal fishes are predominately herbivores or omnivores (Helfman, 1978). Diel rotation of niches, such as the broad replacement of diurnal planktivores during the night shift, proceeds in well-timed fashion (Hobson, 1972). Some of the largest schools encountered by day in tropical waters are nonfeeding, resting schools of nocturnal fishes, while many diurnal fishes actively school in the water column by day and then rest individually at night (Hobson, 1965; Parrish, 1992).

Activity patterns of fishes tend to be less clearly defined in communities found on temperate rocky banks compared to those on tropical reefs (Helfman, 1978; Hobson et al., 1981). Similar to activity patterns observed in tropical areas, diurnal planktivores and omnivores pack the water column above the bank and then seek refuge during the night, but this space is only partly reoccupied at night by mostly large-eyed species (Ebeling and Bray, 1976; Hobson and Chess, 1976; Moulton, 1977). Also, no inactive (resting) schools are observed over rocky banks during the day although some nocturnal individuals may be found in holes (Ebeling and Bray, 1976). Aggregations of fishes just above prominent, larger-size substratum seem to diminish during the night, and species tend to seek shelter within crannies around larger substratum rather than moving out over sand flat areas (Ebeling and Bray, 1976; Hobson and Chess, 1976). Researchers have postulated that the lack of activity during the night in temperate areas may be due to the lack of faint moonlight, which illuminates clear tropical waters allowing for more specialized activities (Ebeling and Bray, 1976; Moulton, 1977).

Abundance and activity patterns in some species of fishes persist in deeper temperate areas. On Stonewall Bank, Oregon, *in situ* direct observations showed that species composition changed little from day to night, but the abundance of some fishes decreases dramatically (Hixon and Tissot, 1992). Specifically, juvenile (*Sebastes spp.*) and rosethorn rockfish (*S. helvomaculatus*) showed considerably greater abundance during the day, and spotted ratfish (*Hydrolagus colliei*) and widow rockfish (*Sebastes entomelas*) were significantly more abundant at night. Hixon and Tissot's (1992) study took place in relatively shallow depths of 41-70 m approximately 37 km northeast of Heceta Bank. Within Pribilof Canyon (181 to 240 m) in the Bering sea, Pacific ocean perch (*S. alutus*) actively fed on euphausiids just above sea whip "forests" during the day, and were observed to be less active within the sea whip habitat at night

(Brodeur, 2001). It is not known whether an overall change in activity from day to night, similar to what is observed in shallow temperate fish communities (Ebeling and Bray, 1976; Hobson and Chess, 1976; Moulton, 1977), exist in deeper rocky bank areas at lower levels of ambient light.

I hypothesized there would be differences in the day and night assemblages of fishes, but that the patterns and changes in activity would be less distinct than those observed in shallow tropical and temperate fish communities. In order to test this hypothesis, the objectives of this study were to: (1) Measure the abundance, distribution, and activity levels of demersal fishes on Heceta Bank between day and night periods among different depths and habitats, and (2) Determine differences in availability of demersal fishes to surveys with the remotely operated vehicle (ROV) between day and night periods among different depths, habitats, and stations. If there are significant diel differences in availability of certain demersal fishes to *in situ* direct counting, then there may be a bias in direct-count surveys with restricted temporal sampling.

MATERIALS AND METHODS

Heceta Bank Project Background

Heceta Bank, Oregon has been a primary focus of *in situ* studies of groundfishes, invertebrates, and habitat since the late 1980's (Fig. 1.1) (Hixon et al., 1991; Hixon and Tissot, 1992; Nasby, 2000; Pearcy et al., 1989; Puniwai, 2002; Romsos, 2004; Stein et al., 1992; Tissot et al., in revision; Whitmire, 2003). Hixon et al. (1991) investigated relationships between fish and invertebrate taxa, depth, and habitat using the occupied submersible Delta in the fall of 1988, 1989, and 1990, establishing six historical stations on the bank. In 2000 from June 19-26, scientists revisited five of these historical stations and explored new areas of the bank with the ROPOS (Remotely Operated Platform for Ocean Science) ROV to perform diel surveys. Day and night fish transects were located at historical stations (Hixon et al., 1991) to link this study to previous *in situ* research on fish communities. Anecdotal evidence from previous submersible and ROV surveys along the U.S. West Coast suggested greater abundance and activity of fishes during day compared to night.

Study Area

Heceta Bank is the largest of all submarine, rocky banks off the coast of the Pacific Northwest, and thus is an ideal location for studying diel patterns in the distribution, abundance, and activity of demersal fishes among different depths and habitat types (Fig. 1.1). It is located approximately 60 km off the central Oregon coast, extending 50 km north to south. The bank ranges in water depth from 70 m at the top to 700 m along its western flank. Due to its large size, Heceta Bank greatly influences shelf transport of water masses, both in alongshore and across-shelf directions (T. Cowles, personal communication, Oregon State University). Eddies commonly form around Heceta Bank, retaining patches of high chlorophyll concentrations (up to

$7 mg/m^3$) at the surface (Barth et al., in review). Hixon et al. (1991) and others have identified a wide variety of bottom types, including mud, sand, cobble and boulder substrata (Tissot et al., in revision). The bank has been generally characterized as having three major habitat-depth profiles: (1) Shallow rock ridge and boulder habitat from 70-100 m, (2) mid-depth boulder and cobble habitat from 100-150 m, and (3) deep mud habitat in greater than 150 m of depth (Hixon et al., 1991). Some portions of the bank show high habitat variability (Tissot et al., in revision).

Survey Transects

Video transects were conducted using an advanced ROV developed for scientific studies. The *ROPOS* is a 30-horsepower electro-hydraulic ROV equipped with a broadcast quality Sony DXC 950 three-clip color video camera, wide angle low light video, three arc lights (250 Watts each), four halogen lights with adjustable intensity (250 Watts each), obstacle avoidance sonar, compass, as well as a 10-horsepower cage with separate light and video systems. One pair of scaling lasers (10 cm scale) mounted on the camera assisted in estimating fish and rock size, as well as transect width and habitat patch dimensions. Distance surveyed was determined from smoothed ultra-short baseline navigation track. Audio commentary of habitat type and fish identification was overlain on video. The *ROPOS* ROV was an ideally suited for surveying day and night abundance and behavior of fishes as the ROV's support personnel routinely conducted 24-hour operations.

The *ROPOS* ROV was used for all fish transect surveys. Non-random transect locations were used in order to maintain consistency with previous historical studies (Hixon et al., 1991; Pearcy et al., 1989; Stein et al., 1992; Tissot et al., in revision). Most day transects were run over the same survey lines during night, but some did not overlap succinctly due to strong currents. Day-night complements were completed outside the two-hour twilight periods of dawn (4:36 to 6:36AM PST) and dusk (8:06 to 10:06PM PST) to avoid possible biases due to changes in the behavior of fishes (Hobson, 1972; Yoklavich et al., 2000; see chapter 2). All of the daytime fish transects overlapped geographically or were in close proximity to the corresponding night fish transects, except for one dive that occurred only during the day in station 1, one dive that occurred only during the night in station 8, and day and night complements that occurred at different depths at station 10 (Fig. 1.2). These three stations were not used in the analysis. Station 4 contained a night transect located approximately 250 m away but at similar depth and over similar habitat, and thus was included in the analysis.

The five stations used in this study range in location from on top of the bank to halfway down the flank of the bank. Stations 3 and 9 are the two shallowest stations located on the ridge of the bank over mostly boulder, cobble, and rock ridge substrata. Station 3 is located on the south portion of bank while station 9 is positioned at the north end with depths ranging from 72-126 m (90 m average) and 101-126 m (110 m average), respectively. Stations 4 is located at the top of the banks' slope placed primarily over rock ridge and mud substrata with depths ranging from 114-200 m (140 m average). Stations 2 and 6 stretch halfway down the slope of the bank and are situated over primarily cobble and mud substrata. Depths for stations 2 and 6 range from 147-174 m (157 m average) and 136-341 m (183 m average), respectively.

Video Analysis

All video was analyzed for fish and habitat identification and entered into an access database. Only stations 2, 3, 4, 6, and 9 where dives had day-night complements of similar depth and proximity were used in the analyses (Fig. 1.2). Sunset, dawn, dusk, and nautical twilight times (Pacific daylight savings time) were derived using the U.S. Naval Observatory website (U.S. Naval Observatory, 2004). These times were calculated for the day of each dive using the specific longitude and latitude coordinates (degrees and minutes) for each station.

Video from all transects were divided into habitat patch segments by using a binary classification system (Hixon et al., 1991, Stein et al. 1992). Substrata were categorized within each transect using six standardized codes: rock ridge (high rugosity, >3.0m), flat rock (low rugosity), boulder (3.0m-25.6cm), cobble (25.6-6.4cm), pebble (6.4-0.2cm), sand (2.0-0.06mm), and mud (<0.06mm). The first code described the primary cover ($\geq$50% of the substrata) in the field of view, and the second code indicated the secondary cover (20-50% of the substrata). Combined, the two codes describe a section of uniform substrata defined as a habitat "patch". The length of each habitat patch was determined using the geographic position recorded at the start and end of each patch. Using the scaling lasers, the width of each transect was estimated by selecting random frames every minute in each transect, measuring the width of these lasers on the video monitor, and extrapolating that to the effective field of view. The area of each patch was determined by multiplying the patch length by the average patch width. Each transect consisted of many habitat patches, depending on the variability of substrata.

All fishes were assigned a taxa identification, counted, and assigned an approximate length and activity code. Paired lasers mounted on the camera assisted in estimating length of fishes. All taxa representing $\geq$0.1% of the total day and night abundance (number of fish per hectare) were used in the analysis (except unknown fish) and most taxa under this value were excluded. Darkblotched rockfish (*S. crameri*) were $\leq$0.1% of the total day and night abundance but were included in the analysis as they are an important commercial species. Kelp greenling (*decagrammus*) and bigfin eelpout (*Lycodes cortezianus*) also showed $\leq$0.1% of the total day and night abundance, but were included in the analysis as their diel activity has been studied in shallow temperate areas (Moulton, 1977). Unknown (unidentified) fish were excluded from the analysis. Thirty-one fish taxa were included, and 19 were excluded. Some taxa categories were created, such as "pygmy-Puget Sound complex" and "unknown rockfish", where it was impossible to identify each individual in dense schools or identify a particular fish conclusively. Also, some species were indistinguishable on video but belonged to a similar *genus* or *family*, such as most unknown cottids. All flatfish were excluded from the activity analysis as we observed very little activity in flatfish. Two simple activity categories were developed in order to analyze the video efficiently and quantitatively, as measuring fish activity accurately from dive surveys can be difficult (Adams et al., 1995; Hobson, 1972; Moulton, 1977). All fishes were placed into one of two categories: active and off the bottom (or temporarily in contact with the substrata), or inactive and in contact with the substrata (sitting on the seafloor or hiding). Two assumptions were involved when analyzing the video for activity of all fishes; (1) Individual fish were not counted twice within a given transect unless otherwise noted on the audio commentary, and (2) the submersible did not influence the activity of most fishes unless the fish was in direct contact with the submersible or exhibited erratic movement (e.g. attempting to avoid predation) (Adams et al., 1995). The change in behavior by a few fish taxa, such as canary and yellowtail rockfish that tended to follow the ROV, was taken into account by not counting individuals twice that were observed to be attracted to the ROV (Wakefield and Parker, 2001). When the ROV clearly affected the activity of a fish, the activity of the fish before the interruption was used. At the very least, any change in the behavior of fishes caused by the presence of the ROV was consistent between stations, depths, and day and night periods (Hixon et al., 1991).

Data Analysis

We used the Wilcoxon sign-ranked test (Ramsey, 1997) to determine significant differences in abundance between day and night across all stations (stations 2, 3, 4, 6, and 9) and within the four most dominant primary habitat types (Rock ridge, Boulder, Cobble, and Mud). For abundance across all stations for each taxon, abundance between day and night was compared within each station (total of 5 comparisons per primary habitat type). For abundance of each taxon over each primary habitat type, abundance between day and night was compared between habitat patches over similar primary habitat type and location. For all taxa, 402 habitat patches were analyzed, with an average of 16 habitat patches compared for each taxon. This enabled us to determine any marked differences in abundance for each taxon across all stations, over the four most dominant primary habitats, and to estimate if abundance trends were consistent at both scales.

We also used the Wilcoxon sign-ranked test to determine significant differences between the percent of fishes active versus inactive during day and night for each taxon over similar primary habitat types. For each primary habitat type and taxon, the percent of active fish were compared with percent of inactive fish within the same habitat patch during day and night. A total of 467 habitat patches during day and 569 habitat patches during night were analyzed for all taxa, with an average of 36 and 41 habitat patches compared for each taxon during day and night, respectively. This enabled us to determine if any taxon was significantly more active or inactive during day and night, indicating diurnal or nocturnal activity patterns.

We used NMS (Nonmetric Multidimensional Scaling) to examine specific associations between day and night abundance of fishes and depth, and day and night abundance of fishes and primary habitat (McCune et al., 2000). Only taxa that showed significantly greater abundance during day or night in the Wilcoxon sign-ranked test (p-value < 0.05), and showed a correlation with depth ($R <$ or > 0.5 on the second axis) were included in the NMS analysis. A total of 11 taxa met these criteria. Depth was included as a quantitative environmental variable, while day-night and primary habitat type were included as one categorical environmental variable. Sorensen distance measure was used, data were log transformed, and outliers greater than 3.0 standard deviations were excluded from analysis. This test enabled us to determine if marked differences in abundance were associated with depth and primary habitat, and whether taxa showing significantly greater abundance during day or night were distributed similarly on the bank.

RESULTS

A total of 5.5 hectares (40.9 km) were surveyed during 45.6 hours. Shallow areas (70-100 m) were dominated by rock ridge and boulder, mid-depth by cobble, and deeper areas by mud habitat with isolated patches of cobble and boulder (Fig. 1.2). Rock ridge, boulder, cobble, and mud comprised the four most dominant primary habitat types. A total of 29,787 individual fishes were counted. During the day, an average of 207 fishes per hectare were encountered, while during the night an average of 141 fishes per hectare were observed. Fish taxa in greatest abundance were from the genus *Sebastes* (Fig. 1.3). Dominant taxa showed the largest differences in relative abundance between day and night periods.

Across all stations, eight taxa showed significantly greater abundance during the day and five taxa exhibited significantly greater abundance during the night, while 18 taxa did not show any significant difference in abundance between day and night (Fig. 1.3, Table 1.1). Several taxa showed higher abundance during day or night, but low relative abundance precluded statistical significance (Fig. 1.3). A total of six fish taxa were encountered exclusively during day, while seven taxa were encountered exclusively during night.

Day Assemblage

During the day within all stations, large densities of mostly small-size fish taxa were primarily found over shallow rock ridge, boulder, and cobble substrata (Fig. 1.3, 1.4, Table 1.1). Dominant taxa during the day included pygmy rockfish (*S. wilsoni*), Puget Sound rockfish (*S. emphaeus*), pygmy-Puget Sound rockfish (S. *wilsoni* and *emphaeus*), and unknown juvenile rockfish (unidentified *Sebastes* less than 10 cm in length) (Fig. 1.3). These taxa showed significantly greater abundance over medium- to large-size substrata (Table 1.1).

Taxa were placed into five groups: (1) Diurnal, (2) Nocturnal, (3) Significantly more active during day, (4) Significantly more active during night, and (5) Significantly less active during day and/or night. The first two groups indicate complete diel activity patterns, while the last three groups only specify periods of higher or lower activity. Dominant day taxa showed significantly greater activity primarily over medium- to large-size substrata, cobble, boulder, and rock ridge (Table 1.2). Habitat generalists included rosethorn rockfish (Table 1.1), with a significantly greater percent of fish active compared to inactive during the day within three of the five primary habitats, rock ridge, boulder and cobble (Table 1.2). Rosethorn rockfish was the only taxon that exhibited a distinct diurnal activity pattern, as a significantly greater percent of individuals were active compared to inactive during the day, *and* a significantly greater percent of the individuals were inactive compared to active at night.

Night Assemblage

In comparison to the dominant day assemblage, the night assemblage exhibited lower densities consisting of less active, larger-size fishes overall and fewer taxa, many of which were also seen during the daylight hours (Fig. 1.3, Table 1.2). Dominant night taxa included sharpchin rockfish (*Sebastes zacentrus*), yellowtail rockfish (*Sebastes flavidus*), Dover sole (*Microstomus pacificus*), and greenstriped rockfish (*Sebastes elongatus*). Of the dominant night assemblage, sharpchin rockfish comprised over half the night relative abundance (Fig. 1.3) and was the only taxa that showed significantly greater abundance during the night in most primary habitat types (Table 1.1).

Unknown Hagfish (*Eptatretus stoutii or Eptatretus deani*) and spotted ratfish were significantly greater in abundance and activity during the night. Widow rockfish showed significantly greater activity during the night, but did not show a significant difference in abundance as they were rarely observed at night (Fig. 1.3, Table 1.1, 1.2). Hagfish were the only taxa that exhibited a distinct nocturnal activity pattern, with a large number of individuals active during the night while a significant number were inactive during the day.

Nonmetric Multidimensional Scaling Analysis of Distribution

The NMS analysis indicated differences between abundance of taxa among depth, primary habitat, and day and night (Fig. 1.4, Table 1.3). The first three axes described significant patterns among taxa, explaining 78% of the variation found in the final ordination with an acceptable stress value of 20.5. After a +115° rotation, the first axis showed correlation with day (right side with open symbols) and night (left side with filled symbols) sample units, explaining 22% of the variation in the data. The second axis, explaining 30% of the variation in the data, had negative correlation with depth (R=0.141) with shallow areas near the top of the second axis. The second axis also had a positive association with habitat size with larger-size primary habitat found in the first and second quadrant of the graph and smaller-size primary habitat in the third and fourth quadrant.

Taxa more abundant during the day (rosethorn rockfish, pygmy rockfish, pygmy-Puget Sound complex, kelp greenling, and unknown juvenile rockfish) showed positive correlation along both axes 1 and 2 and appear in the upper right quadrant of the graph. Puget Sound rockfish showed a correlation to day, but was associated with greater depth and smaller-size primary habitat; these taxa appear in the lower right quadrant. Thus, this dominant day assemblage was mainly observed in shallow- to mid-depths over medium to large-size substrata. Taxa showing greater abundance during the night (spotted ratfish, unknown hagfish, rex sole, sharpchin rockfish, and harlequin rockfish) showed negative correlation along both axes 1 and 2. Thus, the dominant night assemblage was generally over deeper areas of medium- to small-size substrata of cobble and mud.

DISCUSSION

In general, the composition of fish taxa on Heceta Bank did not change dramatically from day to night, but there was a considerable change in the abundance of the four most dominant day taxa (pygmy rockfish, Puget Sound rockfish, pygmy-Puget Sound rockfish, and unknown juvenile rockfish) (Fig. 1.3). Most fish taxa showed significantly greater abundance and activity during the day than at night (Table 1.2). Active, small- to medium-size dominant fish taxa that tended to aggregate around shallow medium- to large-size substrata during the day gave way to less active, larger-size dominant taxa at night (sharpchin rockfish, yellowtail rockfish, Dover sole, and greenstriped rockfish) which were more dispersed at greater depths (Table 1.1, 1.2). Rosethorn rockfish and hagfish, that exhibited diurnal and nocturnal activity, respectively, showed less distinct diel patterns compared to fishes inhabiting shallow temperate or tropical fish communities, as a small number of individuals of each taxon did not rigidly follow a strict diel activity pattern (Table 1.2).

It is likely that fishes found at the top of Heceta Bank perceive and utilize the faint sun illumination during day (Boehlert, 1979; L. Britt personal communication, NOAA 2004). During submersible studies conducted on Heceta Bank, sun illumination visible to the human eye extinguished around 100 m of depth (Hixon et al., 1991; Tissot et al., in revision). On Heceta Bank, the photic zone generally extends down to approximately 200 to 300 m water depth (T. Cowles personal communication, Oregon State University 2004) and sun illumination is generally accepted to be utilized by fishes down to these depths (L. Britt personal communication, NOAA 2004). Several species of the genus *Sebastes* on the California coast, the dominant taxa found on Heceta Bank (Pearcy et al., 1989), likely use scotopic vision during periods of faint light intensities found at twilight (Hobson et al., 1981).

During the day, the large abundance of three of the most dominant taxa (pygmy rockfish, pygmy-Puget Sound rockfish, and unknown juvenile rockfish) were correlated to shallow depth (Fig. 1.4), and the high activity of this assemblage was associated with larger primary habitat

(Table 1.2). It is likely that the faint light illumination at the top of Heceta Bank during day contributed towards the higher abundance and activity, as similar studies on temperate species have suggested (Ebeling and Bray, 1976; Hobson and Chess, 1976; Hobson et al., 1981; Moulton, 1977). The dense aggregations of active, small-size taxa in shallow areas over larger substrata, such as boulders and rock ridge (Fig. 1.4), suggests that considerable densities of their prey also exist there during the day (Moulton, 1977). These three taxa are likely visually foraging on smaller-size zooplankton that have migrated down from surface waters to depths found on Heceta Bank (Barth et al., in review), similar to small-size zooplankters that avoid detection of large planktivores but fall prey to juvenile and small-size rockfish on Santa Catalina Island (Hobson et al., 1981).

Light illumination likely also aids the dominant day assemblage as they stay close (perhaps within visual distance) to large substrata that provides refuge from larger, active piscivorous predators. Within Puget Sound, Moulton (1977) observed that juvenile yellowtail rockfish hovering close to large-size substrata during the day, periodically would find refuge from predators around this larger-size substrata. The infrequent occurrence as prey of *Sebastes* in some dominant large piscivorous *Sebastes* by trawl surveys (Adams, 1987; Brodeur and Pearcy, 1984), suggests that large Heceta Bank piscivores may only be exerting low predation pressure on the smaller-size *Sebastes*. Yellowtail and canary rockfish are two of the most abundant large schooling rockfish on Heceta Bank, although juvenile *Sebastes* comprise a low percent by weight of their diet on Heceta Bank (Fig. 1.3) (Brodeur and Pearcy, 1984). Widow rockfish feed primarily at day and their stomach contents include a high percent of fishes, but *Sebastes* represent only a small percent (Adams, 1987).

The changeover to a dominant assemblage of generally larger-size taxa at night corresponded to a decrease in overall activity, suggesting that diel niche partitioning of habitat and prey is occurring on Heceta Bank (Fig. 1.3, 1.4, Table 1.2). The night assemblage was defined mostly by the absence of taxa in high abundance during day, as all of the dominant taxa encountered during night showed similar abundance between day and night, except for sharpchin rockfish. The compromise in vision and the greater abundance of larger, active predatory taxa likely contributed to the small- to mid-size *Sebastes* taxa evacuating the water column (Helfman, 1978). The increase in larger-size taxa at night may indicate the migration of fishes from greater depths (M. Hixon personal communication, Oregon State University 2004; Brodeur and Pearcy, 1984), but there was no evidence (Table 1.2) for a replacement of diurnally active taxa similar to fish communities on shallow rocky banks of Catalina Island (Hobson and Chess, 1976; Hobson et al., 1981) and Hawaiian tropical reefs (Hobson, 1965, 1972).

The majority of fish taxa did not exhibit distinct diel activity patterns (Table 1.2), but rosethorn rockfish showed a fairly complete diurnal activity pattern, and hagfish exhibited a nocturnal activity pattern similar to Ooka-Souda et al.'s (1985) observations of *Eptatretus burgeri* in the lab. This suggests that marked differences in diel activity are not selected for to the extent found in shallow tropical coral reef and temperate fish communities (Helfman, 1978; Hobson, 1972). The diurnal activity pattern exhibited by rosethorn rockfish was independent of habitat, suggesting that habitat type may not be a significant factor in determining differences between day and night activities of fishes on Heceta Bank (Table 1.1, 1.2). During the day on Heceta Bank, most hagfish were observed coiled up over mud or sand or around cobble, while during the night they were observed swimming above bottom or moving in contact with bottom in a twisted manner. This taxon only possesses photoreceptors and has a primitive mouth, fitting the model of a nocturnal fishes (Helfman, 1978). Spotted ratfish exhibited significantly greater abundance and activity during night, comparable with abundance (Hixon et al., 1992) and activity (Moulton, 1977) patterns found in other temperate studies. As not all rosethorn rockfish and hagfish strictly followed a diurnal or nocturnal activity pattern, respectively, it is likely that overriding mechanisms are at work, such as feeding or the change in water turbidity affecting downwelling light (Collette and Talbot, 1972; Ebeling and Bray, 1976; Moulton, 1977). In addition, the activity measure we used may not have been sensitive enough to detect subtle changes in behavior, such as resting individuals found floating close to but not in contact with larger-size substratum.

Day-night abundance and activity patterns of dominant day and night fish taxa (Fig. 1.3, Table 1.1, 1.2) were similar with diel abundance and activity patterns observed in most shallow temperate fish communities (Helfman, 1978). Most dominant taxa on Heceta Bank exhibited greater abundance and activity during the day, similar to general patterns of larger abundance and higher activity of fishes found over rocky banks at 5 to 20 m of depth off the southern California coast (Fig. 1.3, Table 1.2) (Ebeling in Bray, 1976; Hobson et al., 1981) and rocky banks of Puget Sound at 1 to 15 m depths (Moulton, 1977). The overall marked decrease in abundance and activity during night, similar to what Ebeling and Bray (1976) and Moulton (1977) observed, was not found in Santa Catalina Island (Hobson, 1981) where several species are most active at night. The high abundance and activity of juvenile rockfish during the day and low abundance and activity during the night was similar with findings in kelp forests off Santa Barbara (Ebeling in Bray, 1976) and Santa Catalina Island (Hobson et al., 1981), but the opposite of what Moulton (1977) found on shallow, inshore rocky banks of Puget Sound. The replacement of dominant taxa from day to night on Heceta Bank was not as clearly defined as Hobson et al. (1981) or Moulton (1977) describe, and is more similar to the lack of any broad replacement of taxa that Ebeling and Bray observed (1976).

Abundance, distribution and activity patterns of fishes noted in this study (Fig. 1.3, Table 1.1, 1.2) were similar to those recorded during submersible day surveys on Heceta bank (Hixon et al., 1991; Pearcy et al., 1989; Stein et al., 1992; Tissot et al., in revision) and day and night surveys on Stonewall Bank (Hixon and Tissot, 1992). One of the most consistent observations from previous submersible investigations on Heceta and Stonewall Banks was the dominant large daytime schools of small rockfish species and unknown juvenile rockfish, not present in the survey area during night in this study (Fig. 1.3).

Diel migration of fishes up in the water column and into much deeper areas, and hiding among medium- to large-size substrata, were likely the two most common diel behaviors that decreased the availability of fishes to the ROV. Anecdotal evidence from this study suggests that abundance was underestimated in areas of high densities of fishes over large substrata, and abundance was most accurate in areas of low densities of fishes over small-size, flat substrata of low relief. In some instances, the ROV came very close to the seafloor during day and night, at which time numerous fishes could be seen nestled around the substrata; occasionally the ROV would come in contact with cobble and boulders causing many fishes to appear from openings between rocks. Also, yellowtail rockfish were commonly observed in large schools higher up in the water column during day and night as the ROV would cruise over shallow, rock ridge and boulder areas.

It is more likely that the reduction in abundance of the four most dominant day taxa and sharpchin rockfish during alternate time periods is due to refuge-seeking around medium- to larger-size substrata rather than schooling in the water column, due to the high abundance and activity of large piscivores (Fig. 1.4, Table 1.1) (Adams, 1987; Brodeur and Pearcy, 1984; M. Hixon personal communication, Oregon State University 2004; Wilkins, 1986). In Puget Sound (Moulton, 1977), on rocky kelp forests off Santa Barbara, California (Ebeling and Bray, 1976) and on Santa Catalina Island, California (Hobson and Chess, 1976; Hobson et al., 1981), the small-size and juvenile rockfish that remain exposed during the night stay close to the substrata.

Similar temperate diel studies suggest that larger schooling species make diel migrations, possibly following the diel vertical migration of zooplankton (Baelde, 2001; Hobson et al., 1981). Around Heceta Bank, Brodeur and Pearcy (1984) postulated that large "spikes" in acoustic backscatter during sonar surveys were rockfish schools ascending in the water column to feed during morning hours. Similarly, widow rockfish form dense, midwater schools during the night aggregating around seamounts (Wilkins, 1986), and then disperse during the day at greater depths (Adams, 1987). In contrast, Pacific Ocean perch and other *Sebastes* species feed on euphausiids just above sea whip "forests" during the day, and then migrate into the sea whip habitat at night (Brodeur, 2001). In Puget Sound, schools of black and yellowtail rockfish move down in the water column at night where they are less active (Moulton, 1977). Evidence from this study agrees with previous studies in that widow rockfish showed greater abundance and significantly greater activity during night over boulder primary habitat, but we were unable to determine if these night schools were resting and not actively foraging (Adams, 1987; Hixon and Tissot, 1992; Wilkins, 1986). Yellowtail rockfish did not show any significant difference in abundance between day and night, similar to findings by Hixon and Tissot (1992), and showed significantly greater activity at day over rock ridge and boulder primary habitat similar to Moulton's observations (1977).

Potential bias exists when observing and attempting to quantify activity in fishes when using video survey methods (Sale and Douglas, 1981; Wakefield and Smith, 1990; Uzmann et al., 1977). The majority of studies show that very few fishes exhibit changes in activity with the presence of an ROV or submersible, although a handful of taxa show comparable behavioral responses. In rocky coastal areas along the U. S. west coast, yelloweye rockfish (*Sebastes ruberrimus*) and lingcod (*Ophiodon elongatus*) are attracted to submersibles (Carlson and Straty, 1981). Yellowtail and canary rockfish follow the ROV (Wakefield and Parker, 2001) and submersible (Pearcy et al., 1989). Pacific halibut (*Hipoglossus stenolepis*) act "curious" toward the submersible (High, 1980; Carlson and Straty, 1981) and sculpin (*Cottidae* spp.) gather in moderate numbers while a submersible is motionless (High, 1980). Analogous to ROV surveys, SCUBA video studies suggest that while the majority of fishes show no noticeable reaction, some species may avoid or be attracted to divers outside their field of visibility and may even follow divers (Moulton, 1977). These fishes do not appear to affect counts since the accumulation of fishes remained behind the divers and thus out of the field of view of the camera (Powles and Barans, 1980). In this study, anecdotal evidence suggested this was the case for the

ROV survey, and that the ROV had limited effect on the fishes' behavior except in cases where the ROV came in contact with the substrata.

From what could be viewed in the video, "light shock", a rapid depression of activity in fishes following a sudden exposure to light (Hobson, 1972), had minimal affect on demersal fishes within the survey area. "Light shock" is known to affect both diurnal and nocturnal fishes, while some species show very little to no change in behavior (Ebeling and Bray, 1976; Emery, 1973). During daytime submersible surveys on Heceta Bank in 1988-90, 10-minute rests with all the machinery and lights off determined that there was no discernable difference in fishes' behavior (Stein et al., 1992; Hixon et al., 1991). In general, most researchers have not expressed the opinion that lights from an ROV, submersible, and camera sled alter the behavior of the majority of fishes (Carlson, 1981; Uzmann et al., 1977; Wakefield and Parker, 2001).

Highly significant differences in abundance found in this study suggest that daytime trawl surveys over small- to medium-size substrata may be bias for some taxa. Specifically, Puget Sound rockfish may be more available, while other dominant day taxa (pygmy rockfish, pygmy-Puget Sound rockfish, and unknown juvenile rockfish over shallow, large-size substrata) and sharpchin rockfish are likely less available to trawl surveys. This is assuming that taxa found significantly more abundant in this study over small- to medium-size substrata are more available to trawl surveys over similar habitat. Diel activity patterns in demersal fishes have been shown to dramatically change the catchability of some species in Newfoundland (Casey and Myers, 1998) and in the North Sea (Petrakis et al., 2001). Studies have shown that diel activities in fishes can dictate the timing of fishing (Dorn, 1998), with the most productive and diverse hauls corresponding to a 'feed layer' targeted at daybreak and at the end of the day (Baelde, 2001). In addition, 23% of the U.S. west coast bottom trawl survey area is untrawlable due to areas of high relief, with *Sebastes* species catch rate generally higher in damaged tows (Zimmerman, 2003). During the past few decades, precipitous declines in several stocks of demersal fishes have occurred along the U.S. west coast (Bloeser, 1999). Heceta Bank is centrally located in a major commercial fishery zone off the central Oregon coast, and supports a wide variety of fisheries including demersal trawl, longline, midwater trawl, and a troll fishery (Stein et al., 1992). Thus, the diel activity patterns of dominant day taxa found in this study, which likely includes juvenile *Sebastes* taxa of commercially importance, may influence the availability of these taxa to day trawl surveys around Heceta Bank.

CONCLUSIONS

The changeover from a dominant daytime assemblage of active, small-size taxa that tend to aggregate around shallow medium- to large-size substrata, to a dominant nighttime assemblage of less active, larger-size fishes, suggests that mechanisms operating on temperate shallow rocky banks occur on Heceta Bank. During the day, light and reduced predation pressure likely aids the dominant assemblage in foraging and avoiding larger, active predators with the close proximity to large substrata that provides refuge on Heceta Bank. Rosethorn rockfish were found to be diurnal, hagfish were found to nocturnal, and several other taxa exhibited less complete diel activity and abundance patterns. However, these day-night patterns are less clearly defined than in shallow rocky fish communities along the West Coast, to the extent that most taxa did not show distinct abundance or activity patterns.

This investigation suggests that daytime groundfish trawl surveys may have an important sampling bias for some fishes with significant day-night differences in abundance and activity. The dramatic differences in abundance observed in this study by the dominant day assemblage and sharpchin rockfish should be considered when surveying demersal fishes along the West Coast.

REFERENCES

Adams, P. B.
1987. Diet of widow rockfish *Sebastes entomelas* in central California. In Widow Rockfish, Proceedings of a Workshop. W. H. Lenarz and D. R. Gunderson, Editors. NOAA, NMFS Tech. Rep. Tiburon, California. pp. 37-41.

Adams, P. B., J. L. Butler, C. H. Baxter, T. E. Laidig, K. A. Dahlin, and W. W. Wakefield.
1995. Population estimates of Pacific coast groundfish from video transects and swept-area trawls. Fish. Bull. 93:446-455.

Baelde, P.
2001. Fishers' description of changes in fishing gear and fishing practices in the Australian south east trawl fishery. Mar. and Fresh. Res. 52:411-17.

Barth, J. A., S. D. Pierce, and T. J. Cowles.
In review. Mesoscale structure and its seasonal evolution in northern California current system. Deep Sea Res. II.

Bloeser, J. A.
1999. Diminishing returns: the status of west cost rockfish, Pacific Marine Conservation Council, Astoria, OR, USA, 94pp.

Boehlert, G. W.
1979. Retinal development in postlarval through juvenile *Sebastes diploproa*: adaptations to a changing photic environment. Rev. Can. Biol., 38(4):265-280.

Brodeur, R. D., and W. G. Pearcy.
1984. Food habits and dietary overlap of some shelf rockfishes (Genus *Sebastes*) from the northeastern pacific ocean. Fish. Bull. 2:269-293.

Brodeur, R. D.
2001. Habitat-specific distribution of Pacific ocean perch (*Sebastes alutus*) in Pribilof Canyon, Bering Sea. Cont. Shelf Res. 21:207-224.

Carlson, H. R., and R. R. Straty.
1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes spp.*, in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7):13-19.

Casey, J. M., and R. A. Meyers.
1998. Diel variation in trawl catchability: is it as clear as day and night? Can. J. Fish. Aquat. Sci. 55:2329-2340.

Collette, B. B., and F. H. Talbot.
1972. Activity patterns of coral reef fishes with emphasis on nocturnal-diurnal changeover. Nat. Hist. Mus. Los Ang. Cty., Sci. Bull. 14:98-124.

Dorn, M. W.
1998. Fine-scale fishing strategies of factory trawlers in a midwater trawl fishery for Pacific hake (*Merluccius productus*). Can. J. Fish. Aquat. Sci. 55:180-98.

Ebeling, A. W., and R.N. Bray.
1976. Day versus night activity of reef fishes in a kelp forest off Santa Barbara, California. Fish. Bull. 74:703-717.

Emery, A. R.
1973. Preliminary comparisons of day and night habits of freshwater fish in Ontario lakes, J. Fish. Res. Board. Can. 30:761-774.

Helfman, G. S.
1978. Patterns of community structure in fishes: summary and overview. Env. Biol. Fish. 3:129-48.

High, W. L.
1980. Bait loss from halibut longline gear observed from a submersible. Mar. Fish. Rev. 42(2):26-29.

Hixon, M. A., B.N. Tissot, and W. G. Pearcy.
1991. Fish assemblages of rocky banks of the Pacific Northwest [Heceta, Coquille, and Daisy Banks]. OCS Study MMS 91-0052, USDI Minerals Management Service, OCS Study MMS 91-0052, Camarillo, CA. 195pp.

Hixon, M. A., and B. N. Tissot.
1992. Fish assemblages of rocky banks of the Pacific Northwest [Stonewall Bank]. OCS Study MMS 92-0025, USDI Minerals Management Service, OCS Study, Camarillo, CA. 128pp.

Hobson, E. S.
1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California, Copiea, 3:291-302

Hobson, E. S.
1972. Activity of Hawaiian reef fishes during the evening and morning transitions between daylight and darkness. Fish. Bull. 70(3):715-740.

Hobson, ES.
1974. Feeding relationships of teleostean fishes on coral reefs in Kona, Hawaii. Fish. Bull. 72:915-1030.

Hobson, E. S, and J. R. Chess.
1976. Trophic interactions among fishes and zooplankters nearshore at Santa Catalina Island. Cal. Fish. Bull. 4(3):567-598.

Hobson, E. S., W. N. McFarland, and J. R. Chess.
1981. Crepuscular and nocturnal activities of California nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. Fish. Bull. 79:1-30.

Love, M. S., M. H. Carr, and L. J. Haldorson.
1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Env. Bio. of Fish. 30:225-243.

McCune, B., J. B. Grace, and D. L. Urban.
2000. Analysis of Ecological Communities. MjM Design, Gleneden Beach, Oregon. 3 300pp.

Moulton, L. L.
1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Ph.D. dissertation. University of Washington, Seattle, WA. 182pp.

Nasby, N. M.
2000. Integration of Submersible Transect Data and High-Resolution Sonar Imagery for a Habitat-Based Groundfish Assessment of Heceta Bank, Oregon. MS Thesis, Oregon State University, Corvallis, Oregon. 50pp.

Ooka-Souda, S., H. Kabasawa, and S. Kinoshita.
1985. Circadian rhythms in locomotor activity in the hagfish, *Scarus criocensis*, and the effect of reversal of light-dark cycle. Zool. Sci., 2:749-754.

Parrish, J. K.
1992. Levels of diurnal predation on a school of flat-iron herring, *Harengula thrissina*. Env. Biol. Fish. 34:257-263.

Petrakis, G., D. N. McLennan, and A. W. Newton.
2001. Day-night and depth effects on catch rates during the trawl surveys in the north sea. ICES J. Mar. Sci. 58:50-60.

Pearcy, W. G., D. L. Stein, M. A. Hixon, E. K. Pikitch, W. H. Barss, and R. M. Starr.
1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. Fish. Bull. 87:955-965.

Puniwai, N. P.
2002. Spatial and temporal distribution of the crinoid *Florometra serratissima* on the Oregon continental shelf. MS thesis. Washington State University, Vancouver, WA. 34pp.

Ramsey, F. L., and D. W. Schafer
1997. The Statistical Sleuth, A Course in Methods of Data Analysis. Duxbury Press. 742pp.

Romsos, C. G.
2004. Mapping surficial geologic habitats of the Oregon continental margin using integrated interpretive and GIS techniques. MS thesis. Oregon State University, Corvallis.

Sale, P. F., and W. A. Douglas.
1981. Precision and accuracy of visual census technique for fish assemblages on coral patch reefs. Env. Biol. Fish. 6:333-339.

Stein, D. L., B. N. Tissot, M. A. Hixon, and W. Barss.
1992. Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf. Fish. Bull. 90:540-551.

Tissot, B. N., M. A. Hixon, and D. L. Stein.
In revision. Habitat-based submersible assessment of groundfish assemblages at Heceta Bank, Oregon, from 1988 to 1990. Fish. Bull.

U.S. Naval Observatory.
2004. http://www.usno.navy.mil/

Uzmann, J. R., R. A. Cooper, R. B. Theroux, and R. L. Wigley.
1977. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected mega-fauna: Submersible vs. camera sled vs. otter trawl. Mar. Fish. Rev. 39(12):11-19

Wakefield, W. W., and K. L. Smith, Jr.
1990. Ontogenetic vertical migration in *Sebastolobus altivelis* as a mechanism for transport of particulate organic matter at continental slope depths. Limnol. Oceanogr. 35(6):1314-1328.

Wakefield, W. W., and Parker, SJ.
2001. 'View from the rear view mirror of an ROV', Presentation from 13th Western Groundfish Conference.

Whitmire, C. E.
2003. Using remote sensing, *in situ* observations, and Geographic information systems to map benthic habitats at Heceta Bank, Oregon. MS thesis, Oregon State University, Corvallis, OR. 61pp.

Wilkins, M. E.
1986. Development and evaluation of methodologies for assessing and monitoring the abundance of widow rockfish, *Sebastes entomelas*. Fish. Bull. 84(2):287-310.

Yoklavich, M. M., H. G. Greene, G. M. Cailliet, D. E. Sullivan, R. N. Lea, and M. S. Love.
2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fish. Bull. 98:625-641.

Zimmermann, M.
2003. Calculation of untrawlable' area within the boundaries of a bottom trawl survey. Can J. Fish. Aquat. Sci. 60:657-669.

FIGURES

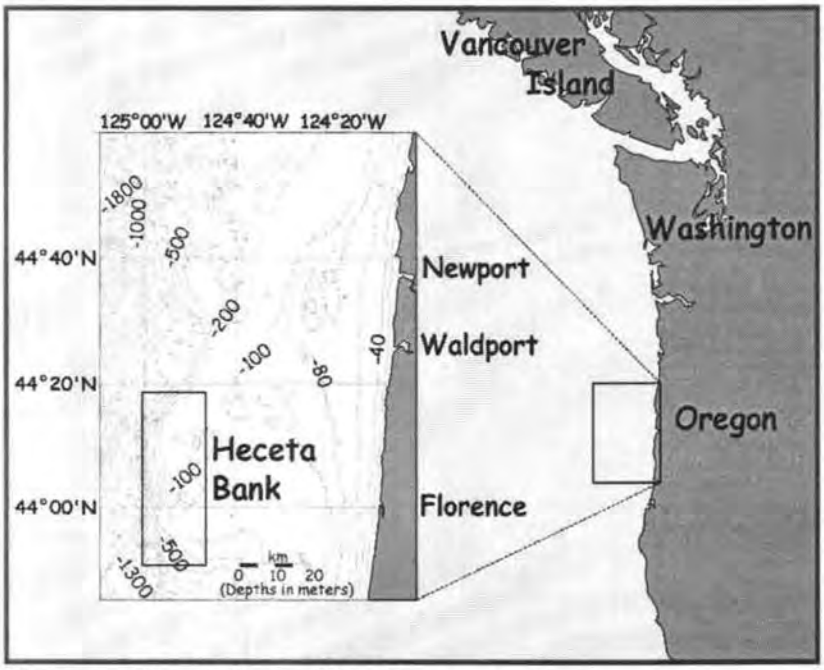


Figure 1.1: Heceta Bank off the Oregon coast.

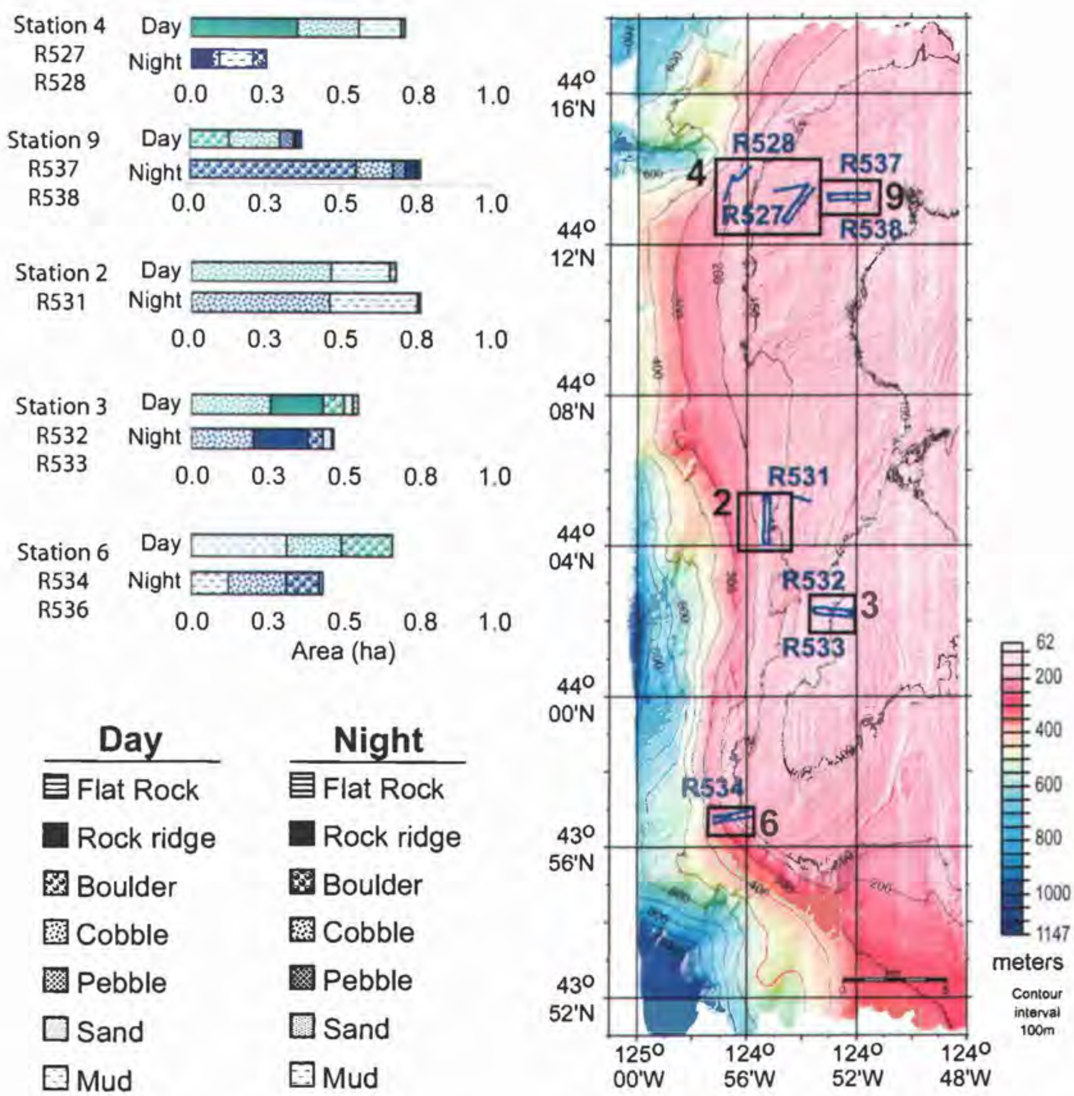


Figure 1.2: Area covered (hectares) of each primary habitat during day and night periods for each station on Heceta Bank, Oregon, during the 2000 ROPOS survey (left panel). Historical stations (boxes) and ROPOS transects overlain on high resolution multibeam bathymetry with a four nautical mile grid (right panel).

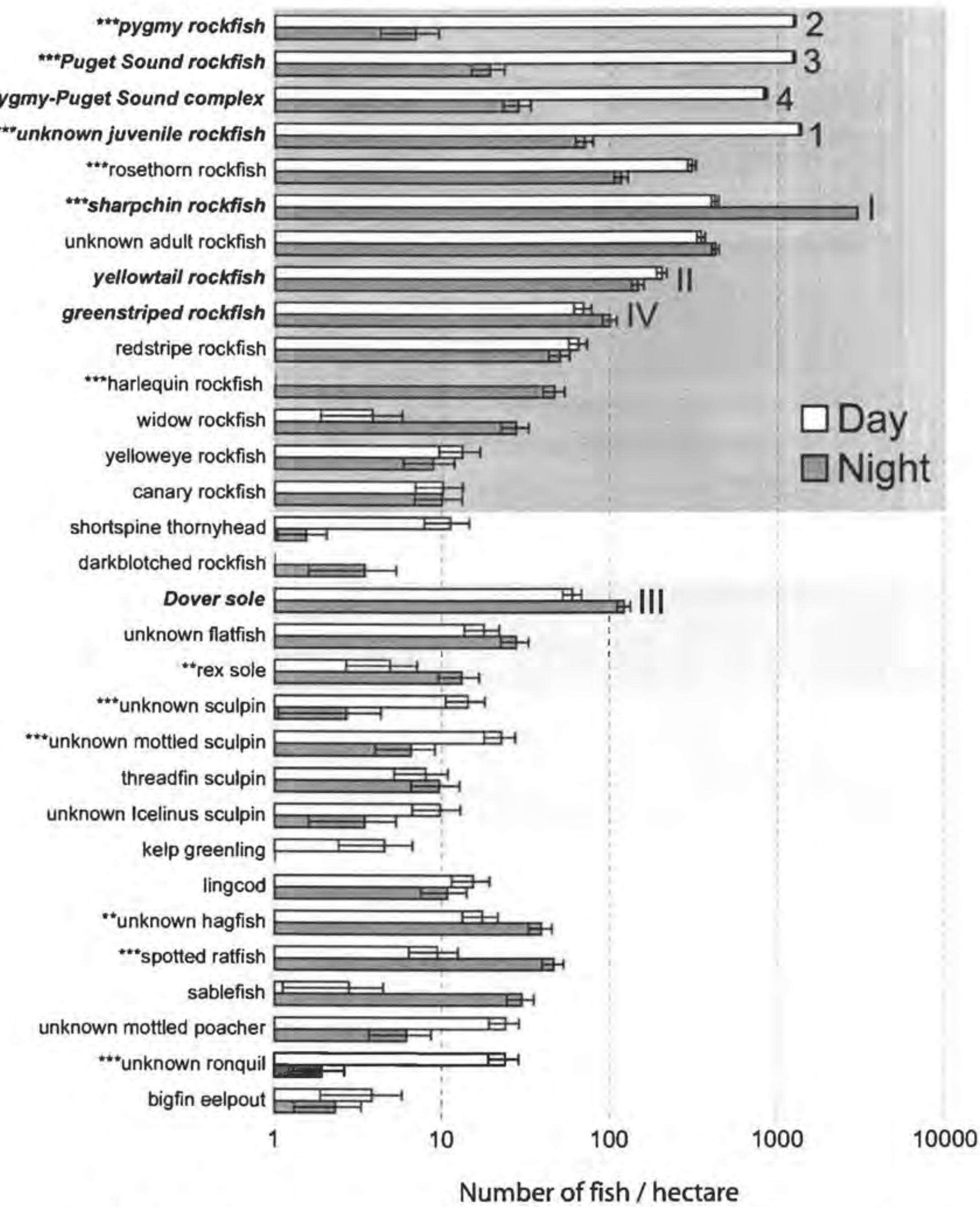


Figure 1.3: Total abundance (number of fish per hectare) of fish taxa (fish taxa >0.1% total abundance plus darkblotched rockfish, kelp greenling, and bigfin eelpout, and minus unknown fish) per hectare encountered during night (grey bars) and day (white bars) over all habitat types within stations 2, 3, 4, 6, and 9. Wilcoxon sign-ranked test was used to compare day and night abundance across each station (2, 3, 4, 6, and 9) (*P<0.05, **P<0.01). Arabic numerals indicate the most dominant taxa during day, and roman numerals indicate the most dominant taxa during night. Error bars indicate standard error for each taxon, where N (number of fish per hectare in each station during day or night) ranged from 9 to 232, with an average of 60.

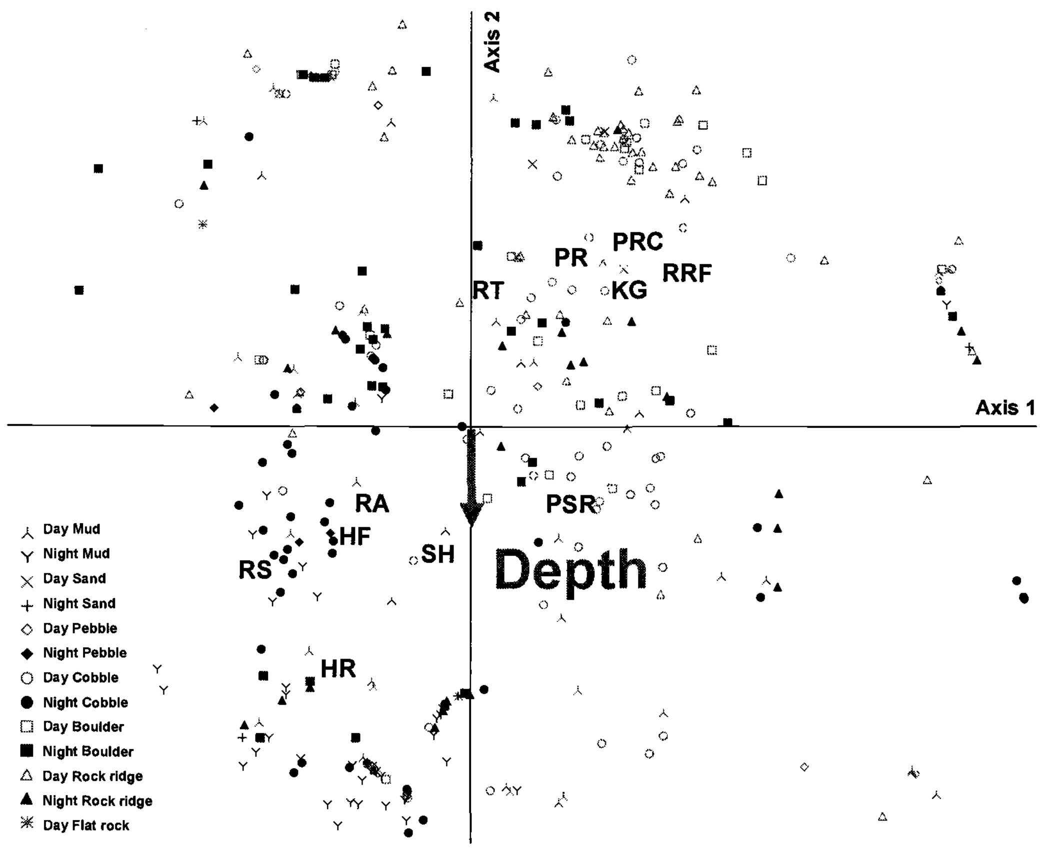


Figure 1.4: NMS (Nonmetric Multidimensional Scaling) ordination. Codes for fishes are: HF (unknown hagfish), HR (harlequin rockfish), KG (kelp greenling), PR (pygmy rockfish), PRC (pygmy-Puget Sound complex), PSR (Puget Sound rockfish), RA (spotted ratfish), RS (rex sole), RT (rosethorn rockfish), RRF (unknown juvenile rockfish), and SH (sharpchin rockfish). Environmental variables include the quantitative variable of depth (increasing depth from top to bottom), and the categorical variable of day (open symbols, right) and night (closed symbols, left), and habitat (shape of symbols).

TABLES

Table 1.1: Fish taxa exhibiting significantly greater abundance (number of fish per hectare) across all stations (2, 3, 4, 6, and 9) over primary habitat types (rock ridge, boulder, cobble, and mud) during day or night. Wilcoxon sign-ranked test was used to compare day and night abundance between habitat patches in closest geographic proximity within primary habitat types over all stations. Taxa are listed in order of abundance, and primary habitat is listed in decreasing order of size.

Taxon	Primary Habitat	p-value
Significantly more abundant during day:		
unknown juvenile rockfish	Rock ridge	0.001
	Boulder	0.025
	Cobble	< 0.001
	Mud	0.013
Puget Sound rockfish	Cobble	< 0.001
	Mud	< 0.001
pygmy rockfish	Rock ridge	< 0.001
	Boulder	0.020
	Cobble	< 0.001
pygmy-Puget Sound complex	Rock ridge	0.027
rosethorn rockfish	Rock ridge	0.001
	Cobble	0.017
	Mud	0.011
unknown ronquil	Rock ridge	0.016
	Mud	0.001
unknown mottled sculpin	Cobble	< 0.001
unknown sculpin	Cobble	0.020
	Mud	0.003
unknown mottled poacher	Cobble	0.044
kelp greenling	Boulder	0.043
Significantly more abundant during night:		
sharpchin rockfish	Rock ridge	< 0.001
	Boulder	0.028
	Cobble	0.011
	Mud	0.011
redstripe rockfish	Rock ridge	0.021
harlequin rockfish	Cobble	0.002
spotted ratfish	Cobble	0.021
	Mud	0.021
unknown hagfish	Mud	0.028
	Mud	0.031
rex sole	Mud	0.049

Table 1.2: Fish taxa exhibiting a significant difference in the percent of fish found to be active versus inactive during day and night. Comparisons were made over each primary habitat type (rock ridge, boulder, cobble, and mud) across stations 2, 3, 4, 6, and 9. Values represent the percent of fish found to be active or inactive over each substrate type, while values in parentheses indicate raw abundance for each comparison. Wilcoxon sign-ranked test was used to compare the percent of fish found to be active versus inactive in similar habitat patches within similar primary habitat types during day and night over all stations (*P<0.05, **P<0.01). Taxa are listed in order of abundance (number of fish per hectare) within each category, and primary habitat is listed in decreasing order of size for each taxon.

Taxon	Primary Habitat	Day Active	Day Inactive	Night Active	Night Inactive
Diurnal:					
rosethorn rockfish	Rock ridge	76% (246)**			ns
	Boulder	74% (243)*			85% (123)**
	Cobble	66% (405)*			92% (143)**
	Mud	ns			93% (47)**
Nocturnal:					
unknown hagfish	Cobble		87% (23)*	69% (29)*	
Significantly more active during day:					
pygmy rockfish	Rock ridge	99% (855)**			
	Cobble	99% (235)**			
	Mud	94% (34)**			
unknown juvenile rockfish	Rock ridge	99% (1018)**			
	Boulder	98% (1214)**			
	Cobble	96% (876)**			
	Mud	91% (54)**			
Puget Sound rockfish	Boulder	71% (367)**			
	Cobble	73% (2501)**			
	Mud	87% (126)**			
yellowtail rockfish	Rock ridge	95% (259)**			
	Boulder	96% (260)**			
Significantly more active during night:					
spotted ratfish	Boulder			87% (16)*	
	Mud			92% (87)*	
widow rockfish	Boulder			96% (45)*	
Significantly less active during day and/or night:					
sharpchin rockfish	Rock ridge		ns		95% (118)**
	Boulder		68% (179)*		92% (921)**
	Cobble		89% (850)*		98% (6079)**
	Mud		96% (80)**		95% (626)**
greenstriped rockfish	Rock ridge		67% (27)*		ns
	Cobble		74% (102)**		ns
	Mud		85% (135)**		ns

Table 1.3: Nonmetric multidimensional scaling of abundance for 11 taxa (unknown hagfish, harlequin rockfish, kelp greenling, pygmy rockfish, pygmy-Puget Sound complex, Puget Sound Rockfish, spotted ratfish, rex sole, rosethorn rockfish, unknown juvenile rockfish, and sharpchin rockfish) from stations 2, 3, 4, 6, and 9. Environmental variables include depth (quantitative), day-night (categorical), and habitat (categorical). For each axis, mean stress (the dissimilarity distance between sample units in ordination space), R-square values (increment and cumulative), and p-values are given for the 3 dimensional solution. R-square for depth on the first axis represents Pearson and Kendall Correlation.

		R-squared			
Axes	Mean Stress	Increment	Cumulative	depth	p-value
1	49.769	0.222	0.222	0.141	0.0323
2	29.113	0.301	0.522		0.0323
3	20.487	0.255	0.777		0.0323

Twilight activity patterns in demersal fishes on Heceta Bank, Oregon

Ted Hart

ABSTRACT

During twilight (dawn and dusk), most fishes exhibit a change in activity patterns, often proceeding in a well-defined sequence of behaviors governed by the change in light intensity. During a "quiet period" on tropical reefs, about 20 minutes after sunset and before sunrise, there is often a general decrease in activity of fishes with the exception of crepuscular predators. However, no studies have examined changes in species composition and activity patterns in temperate deepwater habitats during twilight, where the change in light intensity is extremely low. In 2000, a consortium of research organizations conducted surveys overlapping dawn and dusk periods using a remotely operated vehicle (ROV) on Heceta Bank, Oregon. The percent of fishes that appeared active was used as a response variable to determine (1) the timing of any significant increase or decrease in activity, and (2) if there was a marked decrease in activity indicating a quiet period. A significant increase and decrease in the activity of fishes was exhibited during dawn and dusk periods respectively, except for crepuscular predators. During dawn, some fish taxa emerged at different times and showed a more rapid increase in activity compared to other taxa. No clear quiet period was detected, although a 20-minute period of very low activity around nautical twilight was observed. These results suggest that light may be cueing activity patterns in some fishes on Heceta Bank, particularly for diurnal taxa during dawn, but these patterns are much less distinct in comparison to twilight activity patterns found in fish communities on tropical reefs.

INTRODUCTION

Common activity patterns in fishes have been observed during twilight in a wide range of shallow marine systems, from tropical reefs (Hobson, 1972, 1974), to temperate rocky banks (Hobson, 1965; Hobson et al., 1981; Hixon and Tissot, 1992), to inshore rocky banks (Moulton, 1977), involving many different species (Collette and Talbot, 1972; Helfman, 1978). The most noticeable diel change in fishes occurs during dawn and dusk, believed to be driven by entrained circadian rhythms cued by the rising and setting of the sun (Collette and Talbot, 1972; Domm and Domm, 1973). This period marks a transition in which diurnal and nocturnal fish assemblages switch activity levels, and sometimes locations or habitats. The switch can involve various types of migration to and from shelter locations around rocky banks and tropical reefs. During the middle of this changeover, overall activity is reduced on the reef 20 minutes before sunrise and after sunset for approximately 20 minutes (Hobson, 1972). Across studies and geographic locations, researchers have observed a marked reduction in activity during this "quiet period", which may be a result of the reduced visual acuity in both diurnal and nocturnal species (Helfman, 1978; Hobson et al., 1981). Crepuscular predators are most successful at foraging at this time, taking advantage of the compromised vision of their prey (Hobson and Chess, 1976). The overall decrease in the activity of fishes is theorized to be a form of convergent evolution, as a marked reduction in the activity of fishes persists in areas with no crepuscular predators (Helfman, 1978).

No studies to date have investigated activity patterns in demersal fishes during twilight periods on a deep temperate, rocky bank where changes in light are more subtle. With an increase in latitude, activity and assemblage patterns generally become less distinct and species appear to be "less programmed" (Helfman, 1978). For example, along the coast of Santa Barbara, California, tropical families (*Pomacentridae* and *Labridae*) of fishes tend to be more specialized in their night time sheltering behavior, while temperate families (*Scorpaenidae*) tend to exhibit more "lethargic" behavior and remain exposed at night (Ebeling and Bray, 1976). Around Catalina Island, Hobson et al. (1981) noted that some fishes from tropical families would seek and leave nocturnal shelter at precise times during dawn and dusk. Within Puget Sound, most diurnal species show no sequential reduction in activity remaining active during most of the dusk period (Moulton, 1977). These studies suggest that the selection pressures that favor a sequential, marked change in the activity of fishes during twilight in tropical areas are weaker or absent in temperate areas.

In temperate shallow fish communities, researchers have detected a less distinct quiet period, in contrast to the discrete 20-minute period of virtually no activity in fishes observed in tropical areas (Hobson et al., 1981; Moulton, 1977). There appears to be more overlap in periods of activity by diurnal and nocturnal fishes during this 20-minute period. For instance, during dusk within Puget Sound, most fishes show a general reduction in activity (especially by adult rockfishes, but not juvenile rockfishes), crepuscular predators actively forage, and nocturnal species emerge 15-25 minutes after sunset; however, fishes other than crepuscular predators do not show a distinct period of no activity (Moulton, 1977). A number of confounding factors may obscure differences in activity patterns. In general, a greater proportion of temperate fishes are sedentary compared to tropical fishes (Hobson et al., 1981). Also, there are fewer species in temperate habitats than in tropical areas, so there is less competition for diel niche replacement from day to night for specific habitat and prey (Ebeling and Bray, 1976).

Although activity patterns are less distinct in temperate areas, studies suggest that light plays a critical role in fishes' ability to effectively forage and avoid crepuscular predators along the West Coast during twilight. During submersible studies conducted at the end of summer on Heceta Bank, light visible to the human eye is observed to extinguish around 100 m of depth during the day (Hixon et al., 1991; Tissot et al., in revision). At Heceta Bank, the photic zone generally extends down to between 200 to 300 m in clear coastal water and light is generally accepted to be utilized by fishes at these depths (L. Britt personal communication, NOAA 2004;

T. Cowles personal communication, Oregon State University 2004). Several species of the genus *Sebastes* on the California coast, the dominant taxa found on Heceta Bank (Pearcy et al., 1989), likely use scotopic vision during periods of faint light intensities found at twilight (Hobson et al., 1981). Many temperate crepuscular predators have larger cones compared to diurnal eyes and more cones compared to nocturnal eyes, allowing them better acuity when neither the diurnal nor nocturnal eye functions well (Helfman, 1978; Hobson et al., 1981). Thus, it is likely that fishes found at greater depths (>70 m) perceive and utilize the small change in light intensity during twilight (L. Britt personal communication, NOAA 2004).

The objectives of this study were to measure the abundance and activity of demersal fishes on a temperate deepwater rocky bank, Heceta Bank, Oregon, during morning and evening periods in order to: (1) determine any significant increase or decrease in activity, and (2) detect when the change in activity occurs. Specifically, we looked for a marked increase or decrease in the activity of fishes, corresponding to the presence of active crepuscular predators for approximately 20 minutes during dawn and dusk. We hypothesize that a transition from low to high activity in fishes exists during dawn and high to low activity during dusk, as studies have shown a marked increase in activity by several dominant taxa during the day compared to the night on several shallow rocky banks along the West Coast. We also hypothesize that any "quiet period" on Heceta Bank will be less distinct than those observed in shallow rocky banks along the West Coast due to the extremely low change in light intensity during twilight.

MATERIALS AND METHODS

Study Area

See chapter 1 for a general description of the study area (Fig. 2.1).

Survey Transects

See chapter 1 for a comprehensive description of methods used to conduct survey transects. These methods were employed while conducting fish surveys at eight stations (1, 2, 3, 4, 6, 8, 9, and 10), which comprising dawn, dusk and surrounding day and night periods (Fig. 2.2). For purposes of this study, morning refers to 3:00AM-6:30AM and evening to 6:00PM-12:30AM. A 2-hour period was used to define dawn (4:36AM-6:36AM) and dusk (8:06PM-10:06PM), as this encompassed the four twilight phases described in tropical systems where changes in the activity of fishes is most apparent (Helfman, 1978; Hobson, 1972).

During dawn, 0.5 total hectares (3.0 km) were surveyed covering mostly rock ridge, followed by cobble, then boulder substrata over shallow depths (Fig. 2.2, Table 2.1). Station 4 was located on the north end of the bank where 2 dives were conducted (R527 and R528). Station 9 (R538) was also situated on the north portion of the bank with a narrow depth range. Station 3 (R533) was one of the shallowest locations and positioned on the south end of the bank. Night surveys preceding dawn (stations 2, 3, 4, and 9) were over similar habitat, depth, location, and covered similar areas in comparison to dawn surveys. Station 2 was positioned along the top of the slope of the bank.

The two dusk surveys inventoried 0.3 hectares (2.7 km) over mostly deep, mud areas with isolated cobble and boulder patches (Fig. 2.2, Table 2.1). Contiguous night surveys (stations 2, 8, 9, and 10) and day surveys (stations 1, 2, 3, 4, 6, and 9) previous to dusk, covered larger-size substrata in shallower depths in comparison to dusk. The night surveys inventoried similar locations, but the day surveys were located in different stations compared to dusk. Between 8:00PM and 8:45PM very little survey effort was conducted. See the first chapter for a general design of the survey.

Video Analysis

See the first chapter for a comprehensive description of the video analysis methods. All fishes were placed into one of two categories: active and off the bottom (or temporarily in contact with the substrata), or inactive and in contact with the substrata (sitting on the seafloor or hiding). Due to the inability of the ROV to view sheltering areas around larger-size substratum, unlike SCUBA surveys, the low number of fishes observed to be moving in shelter locations were considered active. This criteria is consistent with studies that classify active fishes as moving, exposed and responsive to the presence of divers and inactive fishes as not moving and in contact with the substrata (Ebeling and Bray, 1976; Hobson et al., 1981; Moulton, 1977), but in contrast to similar studies that classify inactive fishes as moving sluggishly while sheltered (Ebeling and Bray, 1976; Hobson et al., 1981; Moulton, 1977).

Data Analysis

All of the four dawn dives within stations 3, 4, and 9 were used, as they overlapped the 20-minute "quiet period" (Fig. 2.2, Table 2.1). During dusk, only dive 536 and 539 (stations 8 and 10, respectively) were used as dive 532 (station 3) did not overlap the "quiet period" (Fig. 2.2). The total morning survey time (3.5 hours) differed from the total evening survey time (6.5 hours) as no surveys were conducted after dawn. Transect lengths ranged from 0.4 to 1.8 km during dawn, 0.4 to 1.7 km during dusk, 0.6 to 2.1 km during day, and 0.1 to 2.2 during night (Table 2.1).

Taxa were identified during dawn and contiguous night periods, and dusk and contiguous day and night periods to look at changes in taxa composition. For purposes of this study, crepuscular predators were identified *a priori* based on earlier studies of feeding ecology and diel activities (Adams, 1987; Brodeur and Pearcy, 1984; Love at al., 2002; Moulton, 1977). These fishes were defined as greater than 30 cm length, actively foraging during twilight, and/or having fishes comprise greater than 10% of their gut contents by weight (including *Sebastes* species) during twilight. These include yellowtail rockfish, lingcod, canary rockfish, yelloweye rockfish, and widow rockfish. Only taxa representing ≥0.1% in abundance of the respective dusk and dawn periods were used in this analysis. Taxa that normally lie motionless on the substrata were excluded from the analysis including Dover sole, unknown flatfishes, Halibut, and rex sole.

To determine general trends in abundance and activity over time, all taxa, except crepuscular predators, were grouped in 2-minute bins for each primary habitat type (rock ridge, boulder, cobble, pebble, sand, and mud). Within each bin the percent of active fishes was calculated with an average of 18 fishes and a range of 2 to 109 fishes per bin. The percent of active crepuscular predators were similarly placed in 2-minute bins, but they were not partitioned by primary habitat type.

Logistic regression was used to determine a significant increase and decrease in activity for all fishes during morning and evening, respectively, except for crepuscular predators. A binomial code was used to indicate active (1) or inactive (0) fishes as a response variable. Fishes length and depth, and time were used as explanatory variables to determine if they had any relationship with activity. A logistic regression line was fit to the binomial data to represent the percent of active fishes over time for morning and evening periods.

RESULTS

Morning

During the 2-hour dawn period, we observed a general trend of increasing activity for most fish taxa (Fig. 2.3). The exception to this pattern was the activity of crepuscular predators, which were mostly active during the entire morning period. This transition from low to high activity occurred from approximately 3:30AM to 6:00AM (2.5 hours), in which the average percent of fishes that were active increased from approximately 3% to 88%. Although the morning survey time encompassed only 3.5 hours, this period covered the transition in activity from the average night activity (3%) to the average day activity (88%). We found a highly significant and positive relationship between the percent of active fishes and time during the 3.5 hour morning period (p-value <0.0001, Table 2.2), indicating that fishes are more active during daylight hours in spite of the relatively small change in light at these depths. Also during this time, a highly significant but negative relationship was found between the percent of active fishes and depth and length of fishes (p-value <0.001, Fig. 2.5a and 2.5b, Table 2.2).

Night surveys, preceding dawn, encountered similar fish taxa, diversity, and densities compared to dawn (Table 2.3). Dominant taxa encountered during the morning period included sharpchin rockfish (*S. zecentrus*), unknown adult rockfish (unidentified *Sebastes* greater than 10 cm in length), unknown juvenile rockfish (unidentified *Sebastes* less than 10 cm), and rosethorn rockfish (*S. helvomaculatus*) (Table 2.3). The most abundant crepuscular predators were yellowtail rockfish (*S. flavidus*), followed by lingcod (*Ophiodon elongatus*) and canary rockfish (*S. pinniger*). Almost all crepuscular predators were active during and leading up to dawn (Fig. 2.3).

No changes in abundance or activity by diurnal, nocturnal, or possible crepuscular predator taxa were found during the quiet period that is identified on tropical reefs (Hobson, 1972), which starts approximately 20 minutes before sunrise (Fig. 2.3). However, there was a 20-minute period of no activity (except for crepuscular predators) during four dives around nautical twilight between 4:07AM and 4:26AM. This period is offset from the tropical interval by approximately 47 minutes. During this period, 37 inactive fishes were found mostly nestled among cobble and pebble while 12 yellowtail rockfish, 5 widow rockfish (*S. entomelas*), and 3 canary rockfish (*S. pinniger*) were actively swimming above the substrate.

Evening

During the 2-hour dusk period, lower activity was observed in comparison to the preceding day periods (Fig. 2.4). During the 6-hour day to night period, a significant and negative relationship was found between the percent of active fishes and time, depth of fishes, and the length of fishes, explaining a high percent (71.4%) of the variation in the data (p-value <0.0001, Table 2.2). This transition from high to low activity occurred from approximately 7:10PM to 12:00AM (4 hours and 50 minutes), in which the average percent of fishes that were active decreased from approximately 88% to 3%. During both morning and evening periods, contiguous day periods showed that a small but noticeable percent of fishes were inactive, while during contiguous night periods very few fishes were active.

In comparison to dusk surveys, similar fish taxa were encountered during contiguous day and night periods, but diversity and density of fishes were much greater (Table 2.3). Fish taxa in greatest abundance during the evening period included pygmy rockfish (*S. wilsoni*), followed by sharpchin rockfish, and pygmy-Puget Sound complex (*S. wilsoni* and *emphaeus*).

Most fishes showed low activity during the tropical quiet period, while the longest period of no activity was during 10:18PM to 10:40PM around nautical twilight (Fig. 2.4). No crepuscular predators were encountered during dusk, but during contiguous day and night periods lingcod, yellowtail rockfish, and widow rockfish were generally active.

DISCUSSION

The gradual and significant increase in activity correlated with time, depth of fishes, and length of fishes during morning suggests similar mechanisms found on shallow tropical reefs and temperate rocky banks, such as circadian rhythms cued by light, may be at work on Heceta Bank (Ebeling and Bray, 1976; Helfman, 1978; Hobson, 1972; Hobson et al., 1981; Moulton, 1977). For instance, fishes at shallower depths were found to be active earlier compared to fishes found at greater depths. Also during dawn, fishes of shorter length became active earlier in comparison to fishes of longer length that exhibited higher activity later on in this period. However, only a few taxa showed an increase in activity over a short time frame that was distinguishable from other taxa.

During morning hours, we were unable to clearly identify a quiet period, defined as a time when both the day and night assemblages vacate the water column and exhibit virtually no activity and crepuscular predators exhibit an increase in activity and foraging (Helfman, 1978; Hobson, 1972; Hobson et al., 1981). The overlap in the activity of fishes during dawn by taxa mostly observed during the day and a few taxa mostly observed at night obscures any period of inactivity at this time (Helfman, 1978). No increase in abundance or foraging activity by crepuscular predators was observed as documented in shallow temperate rocky banks (Moulton, 1977). While fishes are an important part of the diets of canary and yellowtail rockfish (Love et al., 2002), their stomach contents have been found to be fairly empty after dawn around Heceta Bank (Brodeur and Pearcy, 1984). Yellowtail rockfish may be forming resting schools in association with shallow, large-size substrata, as they are known to migrate to greater depths around large substrata during the night showing less activity (Moulton, 1977). Widow rockfish, considered a midwater species, feed during the day and twilight while dispersed at greater depths (400 m), but *Sebastes* species are a very small percent of their diet (Adams, 1987; Wilkins, 1986). Also, Ebeling and Bray observed less predation on fishes during twilight in comparison to day (1976). The combination of lower predation pressure, adequate light intensities, and proximity to larger substrata may allow smaller-size taxa to take advantage of food resources in shallow areas of Heceta Bank during the earlier part of dawn.

The period surrounding nautical twilight was indicative of a quiet period, but crepuscular predators did not exhibit greater densities and were not observed to be actively foraging. Thus, this period does not convincingly fit the definition of a quiet period (Ebeling and Bray, 1976; Helfman, 1978).

During the morning surveys, the dominant taxa encountered were representative of taxa commonly found on Heceta Bank (Hixon et al., 1991; Hixon and Tissot, 1992; Pearcy et al., 1989; Stein et al., 1992; Tissot et al., in revision), and the taxa composition, habitat, and depth remained fairly consistent throughout the 3.5 hour period. This and the similarity in substrata size and taxa diversity and density provided for a suitable analysis of activity, and an appropriate comparison with other shallow rocky bank studies along the West Coast (Ebeling and Bray, 1976; Hobson and Chess, 1976; Hobson et al., 1981; Moulton, 1977).

Activity patterns found during evening were consistent with trends observed during dawn, but were confounded by variable habitat, depth, and taxa diversity and densities. Most notably, the shallow large habitat surveyed during day and night periods does not compare well with dusk surveys over deeper, smaller-size substrata. The highly significant decrease in activity negatively correlated with time, depth of fishes, and length of fishes suggests that mechanisms associated with light intensity may be driving activity patterns similar to what is observed in shallow temperate areas (Ebeling and Bray, 1976; Helfman, 1978; Hobson et al., 1981; Moulton, 1977). Dusk activity patterns were found to be consistent with and in reverse of events observed during dawn. Fishes found at greater depths and of longer length showed a significant decrease in activity at the onset of dusk, while fishes at shallower depths and of shorter length sustained greater activity over the course of the 2-hour dusk period. These trends are likely affected greatly by the fact that day surveys covered the shallow portion of the bank dominated by small *Sebastes* taxa, and the dusk surveys were conducted over deep, small substrata areas dominated by larger, generally less active taxa. Thus, the evidence during this period is suggestive and consistent with patterns found during dawn, but confounding variables make it difficult to draw any meaningful conclusions.

During dawn, it is likely that the small change in light intensity on the top of Heceta Bank is contributing towards the cue that initiates the surge in activity of fishes. This is supported by the fairly consistent taxa composition, habitat, and survey depth covered throughout the 3.5 hour morning period during four dawn surveys. In addition, increasing activity of fishes observed over shallower areas earlier during dawn suggests that fishes are cued by early faint increases in sun illumination before fishes at greater depths, at a time when the eyes of demersal fishes would be most sensitive to a change in light intensity (Helfman, 1978; Hobson et al., 1981). The day assemblage is probably using the faint light intensity in shallow, large substrata locations for foraging in areas of high primary production that afford protection from daytime predators (T. Cowles personal communication, Oregon State University 2004; Barth et al., in review; Hixon et al., 1991; Hixon and Tissot, 1992). Larger taxa were dominant during the night on Stonewall Bank, a shallow (41 to over 71m) northern extension of Heceta Bank, whereas smaller-size taxa are dominant on both Stonewall Bank and shallow areas of Heceta Bank during the day (Tissot et al., in revision; Hixon et al., 1991; Hixon and Tissot, 1992). The greater activity of smaller fishes before larger-size fishes during dawn, likely represents an overlap in activity with a shift from a dominant night to a dominant day assemblage, as most of the fishes encountered during dawn were more active during day or night on Heceta Bank (Hixon et al., 1991; Hixon and Tissot, 1992).

The sequence of smaller-size taxa exhibiting higher activity before larger-size taxa, also suggests that the opportunity and competition for food resources outweighs predation pressure by crepuscular predators for the more vulnerable smaller-size fishes during early dawn. The rapid increase in activity by unknown juvenile rockfish in comparison to the very slow increase by sharpchin rockfish shows a significant difference in the time taken by individual taxa to transition from a generally less active night to a generally more active day period (Domm and Domm, 1973; Helfman, 1978). These patterns imply that light intensities may adequately illuminate the top of Heceta Bank around nautical twilight, at which time the eyes of the smaller-size *Sebastes* assemblage may receive sufficient light to avoid predators and forage (Hobson et al., 1981; Boehlert, 1979).

The marked decrease in activity of fishes and the presence of several large piscivores for approximately 20 minutes surrounding nautical twilight, suggests that predation pressure may be greatest just prior to the general increase in activity during dawn. This earlier period of low activity, in comparison to the tropical quiet period, could be the result of increased competition during dawn with diurnal fishes emerging earlier from shelter to forage during a more precarious period. Increased competition may also be occurring with dominant night taxa, as fishes found to be more abundant and/or active at night were observed to be active during the dawn transition period (Helfman, 1978). The lack of a distinct quiet period may involve higher competition for food with day and night assemblages maximizing time available for feeding and overlapping activity during twilight periods.

Similar to investigations during twilight on shallow, temperate rocky banks (Ebeling and Bray, 1976; Hobson, 1965; Moulton, 1977), we discerned less distinct activity patterns, or phases, than the more precise activity events that have been documented on shallow, tropical reefs (Collette and Talbot, 1972; Domm and Domm, 1973; Hobson, 1972; Hobson and Chess, 1976). Of the three phases that Hobson (1972) discerned on tropical reefs (cover-seeking of nocturnal fishes, quiet period, and the mass emergence of diurnal species), the surge in activity by the day assemblage during dawn was longer and the most distinguishable pattern observed on Heceta Bank. Similar to observations of diurnal fishes at Santa Catalina Island (Hobson et al., 1981) and in Puget Sound (Moulton 1977) during dusk, most day assemblage taxa appeared "less programmed" exhibiting no distinct increase in activity over a narrow time frame that was distinguishable from other taxa.

CONCLUSION

The significant increase in activity of fishes during dawn and the significant decrease in activity during dusk lasted longer (approximately 2.5 to 5 hours respectively) in comparison to twilight events observed on shallow, temperate rocky banks (Ebeling and Bray, 1976; Helfman, 1978; Hobson, 1972; Hobson et al., 1981; Moulton, 1977). During dawn, the earlier activity of smaller fishes found at shallow depths and a possible earlier quiet period suggests that twilight activity patterns are still selected for, likely cued by changes in light intensity and possibly formed by relaxation in predation pressure. Whether the mechanisms driving twilight activity patterns on Heceta Bank are still actively selected for or an evolutionary holdover, they play a large part in determining the interim demersal activity levels of fishes during dawn periods on shallow, mid- to large-size substrata in the vicinity of one of the most important areas for groundfish fisheries off the Oregon coast.

To date ROV and submersible studies along the West Coast have purposely avoided conducting surveys of fishes around twilight to reduce the potential bias caused by changing activity patterns and diel migrations (Hixon et al., 1991; Hixon and Tissot, 1992; Pearcy et al., 1989; Stein et al., 1992; Tissot et al., in revision; Yoklavich et al., 2000). We recommend that surveys of demersal fishes off the Oregon coast avoid dawn periods from 3:30AM to 6:00AM over medium- to large-size substrata during summer months, particularly in depths ranging from 70 to 140 m of depth where the transition in activity can differ up to 45 minutes between taxa.

REFERENCES

Adams, P. B.
1987. Diet of widow rockfish *Sebastes entomelas* in central California. In Widow Rockfish, Proceedings of a Workshop. W. H. Lenarz and D. R. Gunderson, Editors. NOAA, NMFS Tech. Rep. Tiburon, California. pp. 37-41.

Barth, J. A., S. D. Pierce, and T. J. Cowles.
In review. Mesoscale structure and its seasonal evolution in northern California current system. Deep Sea Res. II.

Boehlert, G. W.
1979. Retinal development in postlarval through juvenile *Sebastes diploproa*: adaptations to a changing photic environment. Rev. Can. Biol., 38(4):265-280.

Brodeur, R. D., and W. G. Pearcy.
1984. Food habits and dietary overlap of some shelf rockfishes (Genus *Sebastes*) from the northeastern pacific ocean. Fish. Bull. 2:269-293.

Collette, B. B., F. H. Talbot.
1972. Activity patterns of coral reef fishes with emphasis on nocturnal-diurnal changeover. Los Angels City Natural His Mus. Sci. Bull. 14:98-124.

Domm, S. B., A. J. Domm.
1973. The sequence of appearance at dawn and disappearance at dusk of some coral reef fishes. Pac. Sci. 27:128-135.

Ebeling, A. W., and R.N. Bray.
1976. Day versus night activity of reef fishes in a kelp forest off Santa Barbara, California. Fish. Bull. 74:703-717.

Helfman, G. S.
1978. Patterns of community structure in fishes: summary and overview. Env. Biol. Fish. 3:129-48.

Hixon, M. A., B.N. Tissot, and W. G. Pearcy.
1991. Fish assemblages of rocky banks of the Pacific Northwest [Heceta, Coquille, and Daisy Banks]. OCS Study MMS 91-0052, USDI Minerals Management Service, OCS Study MMS 91-0052, Camarillo, CA. 195pp.

Hixon, M. A., and B. N. Tissot.
1992. Fish assemblages of rocky banks of the Pacific Northwest [Stonewall Bank]. OCS Study MMS 92-0025, USDI Minerals Management Service, OCS Study, Camarillo, CA. 128pp.

Hobson, E. S.
1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California, Copiea, 3:291-302

Hobson, E. S.
1972. Activity of Hawaiian reef fishes during the evening and morning transitions between daylight and darkness. Fish. Bull. 70(3):715-740.

Hobson, E. S.
1974. Feeding relationships of teleostean fishes on coral reefs in Kona, Hawaii. Fish. Bull. 72:915-1030.

Hobson, E. S, and J. R. Chess.
1976. Trophic interactions among fishes and zooplankters nearshore at Santa Catalina Island. Cal. Fish. Bull. 4(3):567-598.

Hobson, E. S., W. N. McFarland, and J. R. Chess.
1981. Crepuscular and nocturnal activities of California nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. Fish. Bull. 79:1-30.

Love, M. S., M. Yoklavich, L. Thorstein.
2002. The rockfishes of the Northeast Pacific. University of California Press, Berkeley, 403 pp.

Moulton, L. L.
1977. An ecological analysis of fishes inhabiting the rocky nearshore regions of northern Puget Sound, Washington. Ph.D. dissertation. University of Washington, Seattle, WA. 182pp.

Pearcy, W. G., D. L. Stein, M. A. Hixon, E. K. Pikitch, W. H. Barss, and R. M. Starr.
1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. Fish. Bull. 87:955-965.

Stein, D. L., B. N. Tissot, M. A. Hixon, and W. Barss.
1992. Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf. Fish. Bull. 90:540-551.

Tissot, B. N., M. A. Hixon, and D. L. Stein.
In revision. Habitat-based submersible assessment of groundfish assemblages at Heceta Bank, Oregon, from 1988 to 1990. Fish. Bull.

Wilkins, M. E.
1986. Development and evaluation of methodologies for assessing and monitoring the abundance of widow rockfish, *Sebastes entomelas*. Fish. Bull. 84(2):287-310.

Yoklavich, M. M., H. G. Greene, G. M. Cailliet, D. E. Sullivan, R. N. Lea, and M. S. Love.
2000. Habitat associations of deep-water rockfishes in a submarine canyon: an example of a natural refuge. Fish. Bull. 98:625-641.

FIGURES

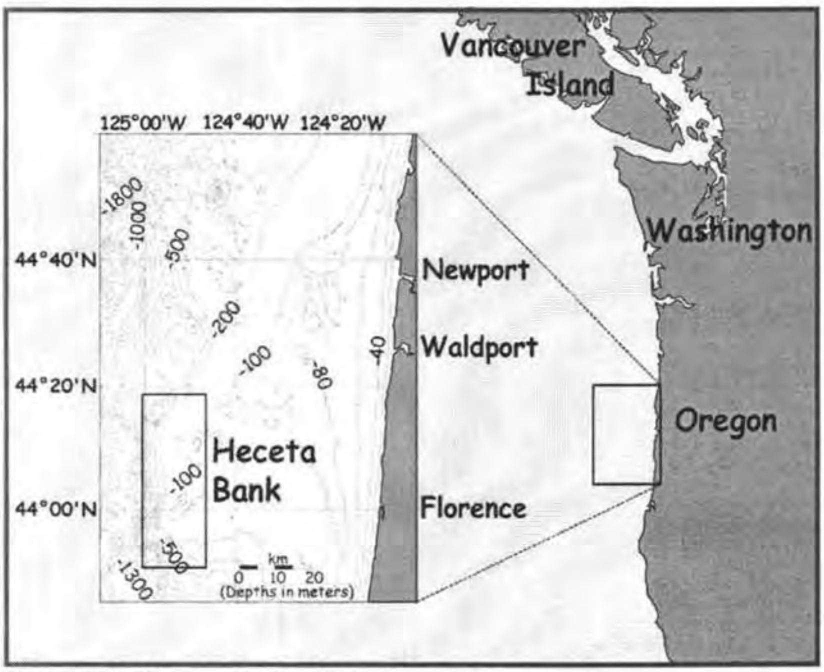


Figure 2.1: Heceta Bank off the Oregon coast.

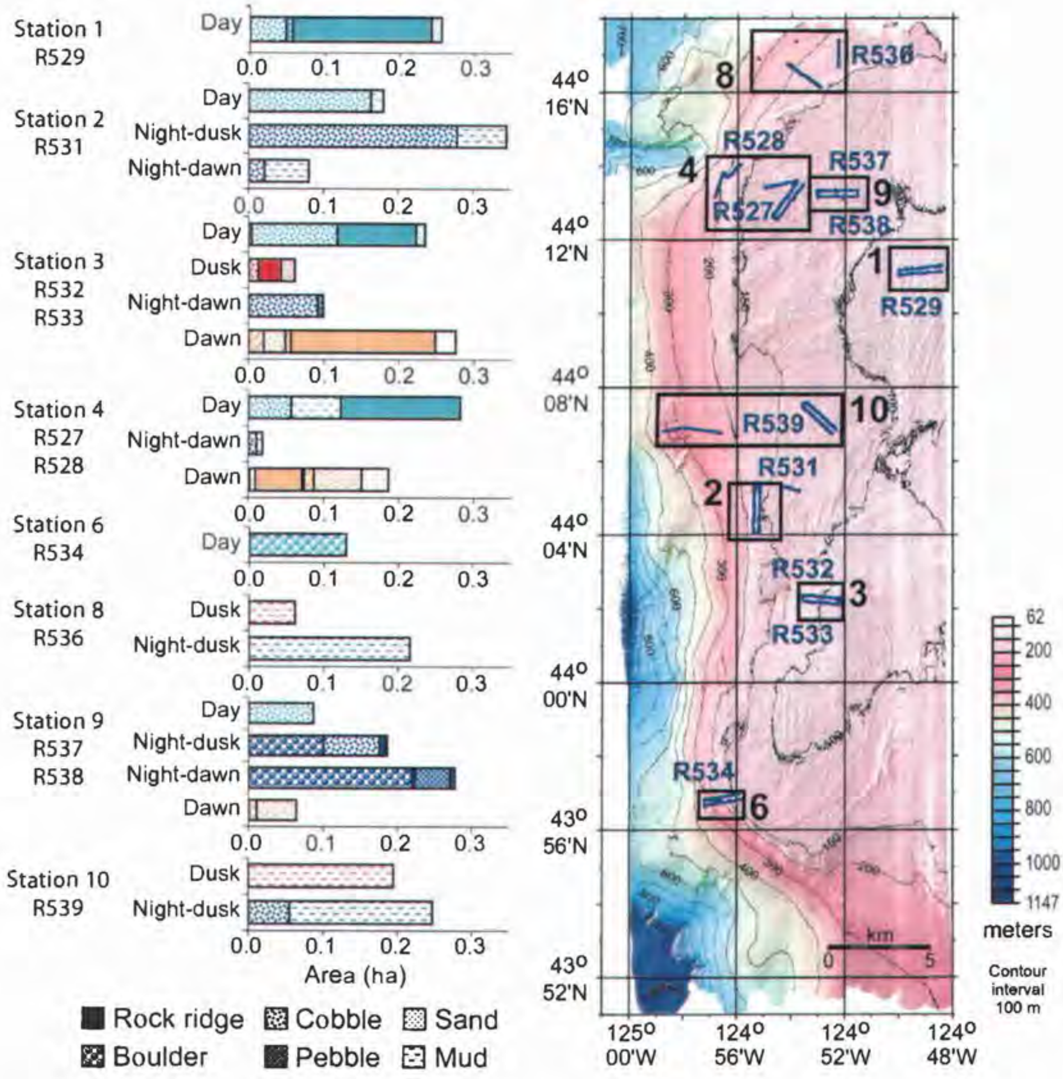
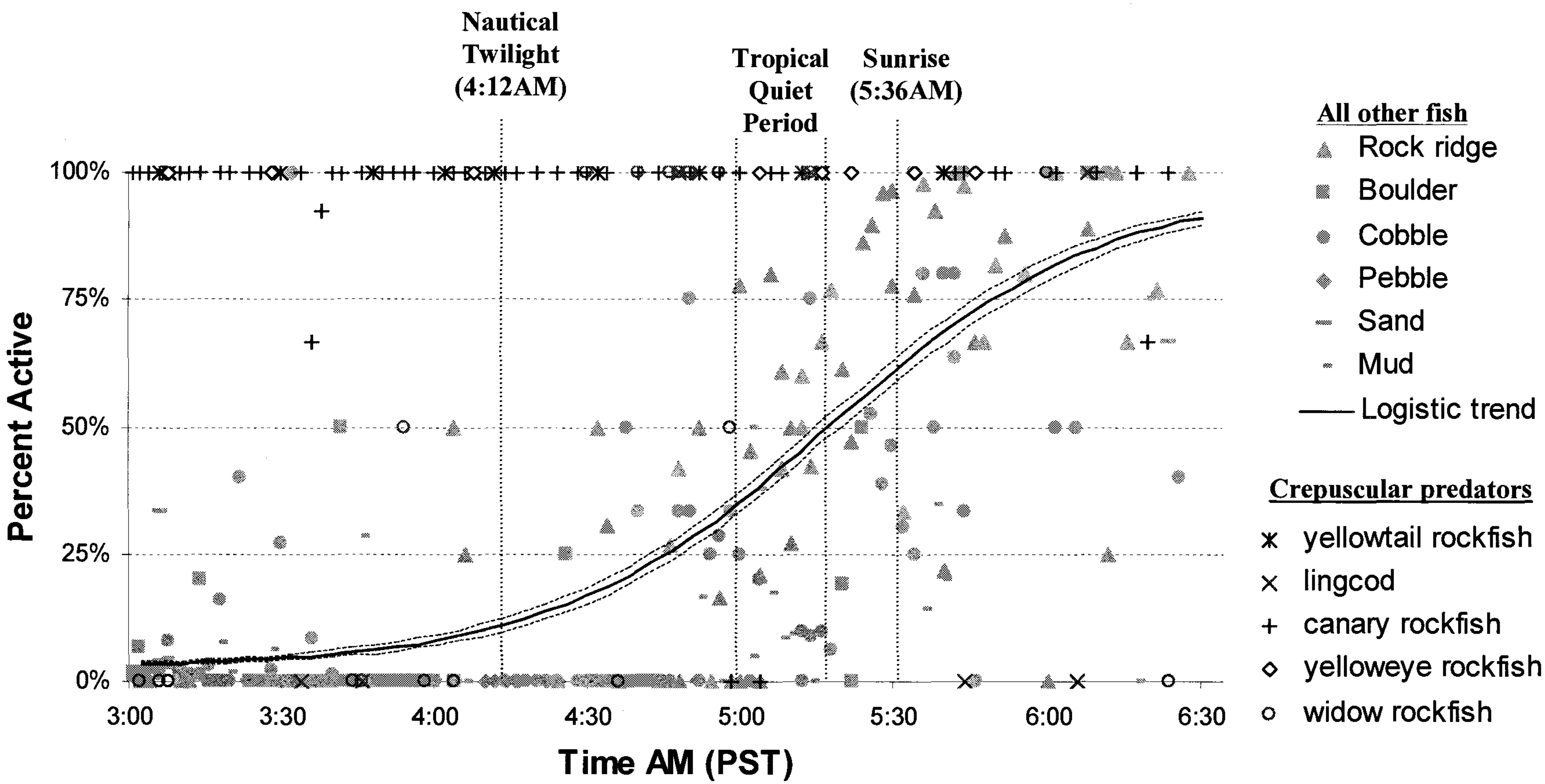


Figure 2.2: Area covered (hectares) of each primary habitat during day, night, dawn, and dusk periods for each station on Heceta Bank, Oregon, during the 2000 ROPOS survey. (left panel). Historical stations (boxes) and ROPOS transects overlain on high resolution multibeam bathymetry with a four nautical mile grid (right panel).

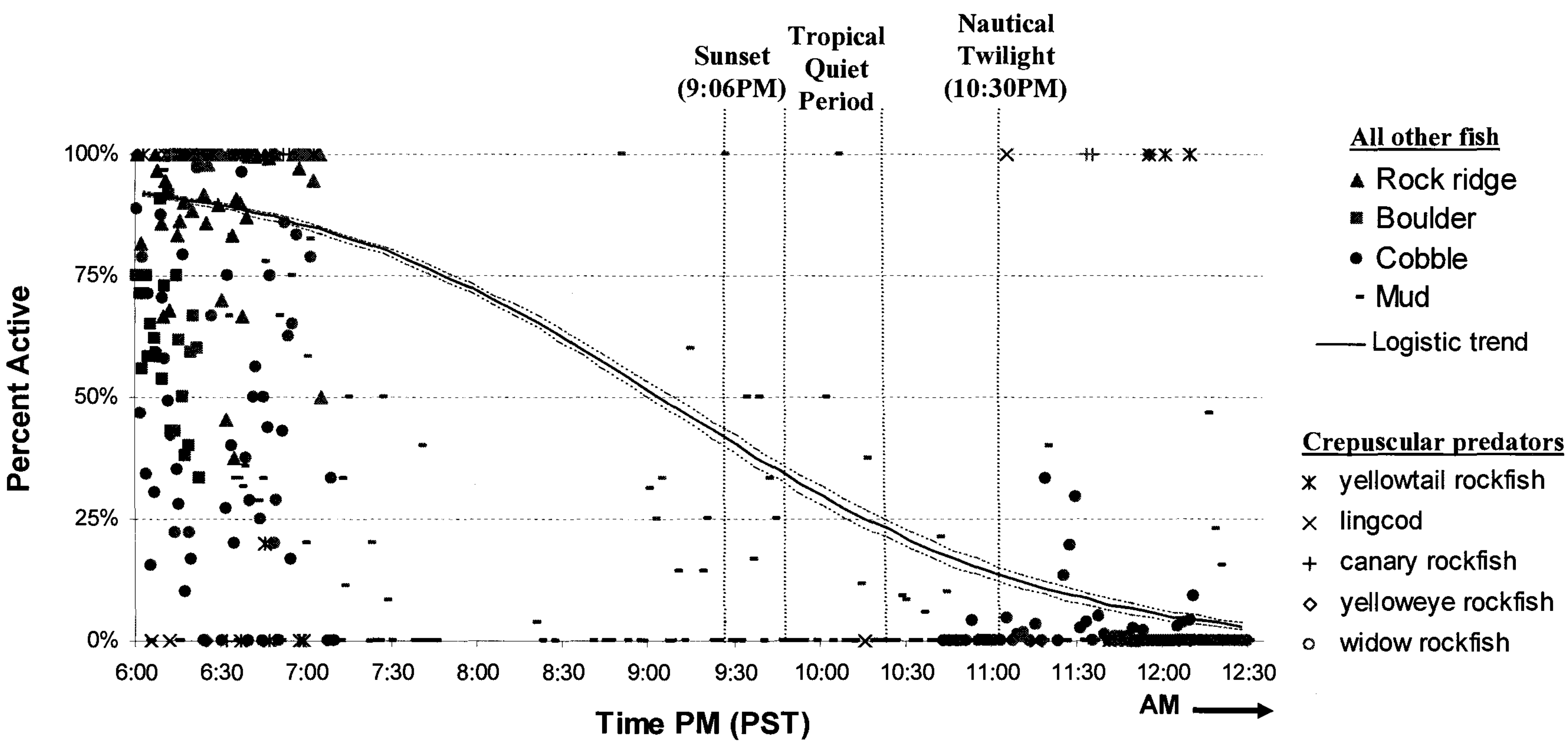
Figure 2.3: Percent of fishes active for all taxa pooled in 2-minute segments over each primary habitat type (except for crepuscular predators). A total of 4 dawn dives (stations 3, 4 (2 dives), and 9, 4:36:00AM to 6:36:00AM PST) and 4 night dives before dawn (stations 2, 3, 4, and 9, 3:00:00AM to 4:36:00AM PST) are shown. A logistic regression line is fit to binomial data for the activity of fishes (active or inactive) of each individual fish (N=4,091), except for the crepuscular predators (N=441). The 95% confidence intervals are represented by dotted lines.



Nautical Twilight (4:12AM)
Tropical Quiet Period
Sunrise (5:36AM)
100%
75%
50%
25%
0%
Percent Active
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
Time AM (PST)
All other fish
Rock ridge
Boulder
Cobble
Pebble
Sand
Mud
Logistic trend
Crepuscular predators
yellowtail rockfish
lingcod
canary rockfish
yelloweye rockfish
widow rockfish

Figure 2.3.

Figure 2.4: Percent of fishes active for all taxa pooled in 2-minute segments over each primary habitat type (except for crepuscular predators). 2 dusk dives (stations 8 and 10, 8:06:00PM to 10:06:00PM PST), 4 night dives after dusk (stations 2, 8, 9, and 10, 10:06:00PM to 12:30:00AM PST), and 6 day dives before dusk (stations 1, 2, 3, 4, 6, and 9, 6:00:00PM to 8:06:00PM PST) are shown. A logistic regression line is fit to binomial activity of fishes (active or inactive) of each individual fish (N=10,540), except for the crepuscular predators (N=188). The 95% confidence intervals are represented by dotted lines.



Sunset (9:06PM)
Tropical Quiet Period
Nautical Twilight (10:30PM)
100%
75%
50%
25%
0%
Percent Active
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00
12:30
AM
Time PM (PST)
All other fish
Rock ridge
Boulder
Cobble
Mud
Logistic trend
Crepuscular predators
yellowtail rockfish
lingcod
canary rockfish
yelloweye rockfish
widow rockfish

Figure 2.4.

Figure 2.5: Percent of active fishes of 4 dawn dives (stations 3, 4, and 9, 4:36:00AM to 6:36:00AM PST) and 4 night dives before dawn (stations 2, 3, 4, and 9, 3:00:00AM to 4:36:00AM PST). A logistic regression line is fit to the binomial activity of fishes (active or inactive) of each individual fish (N=4,091), except for the crepuscular predators (N=441). The 95% confidence intervals are represented by dotted lines

Figure 2.5a: Logistic regression trend line of the percent of active fishes (excluding crepuscular predators) found at 70 m and 100 m depths during morning (top).

Figure 2.5b: Logistic regression trend line of the percent of active fishes (excluding crepuscular predators) measured at lengths of 10.0 cm and 20.0 cm during morning (middle).

Figure 2.5c: Logistic regression trend line of the percent of active fishes (excluding crepuscular predators) for unknown juvenile rockfish (N=535) and sharpchin (N=1,965) rockfish during morning (bottom).

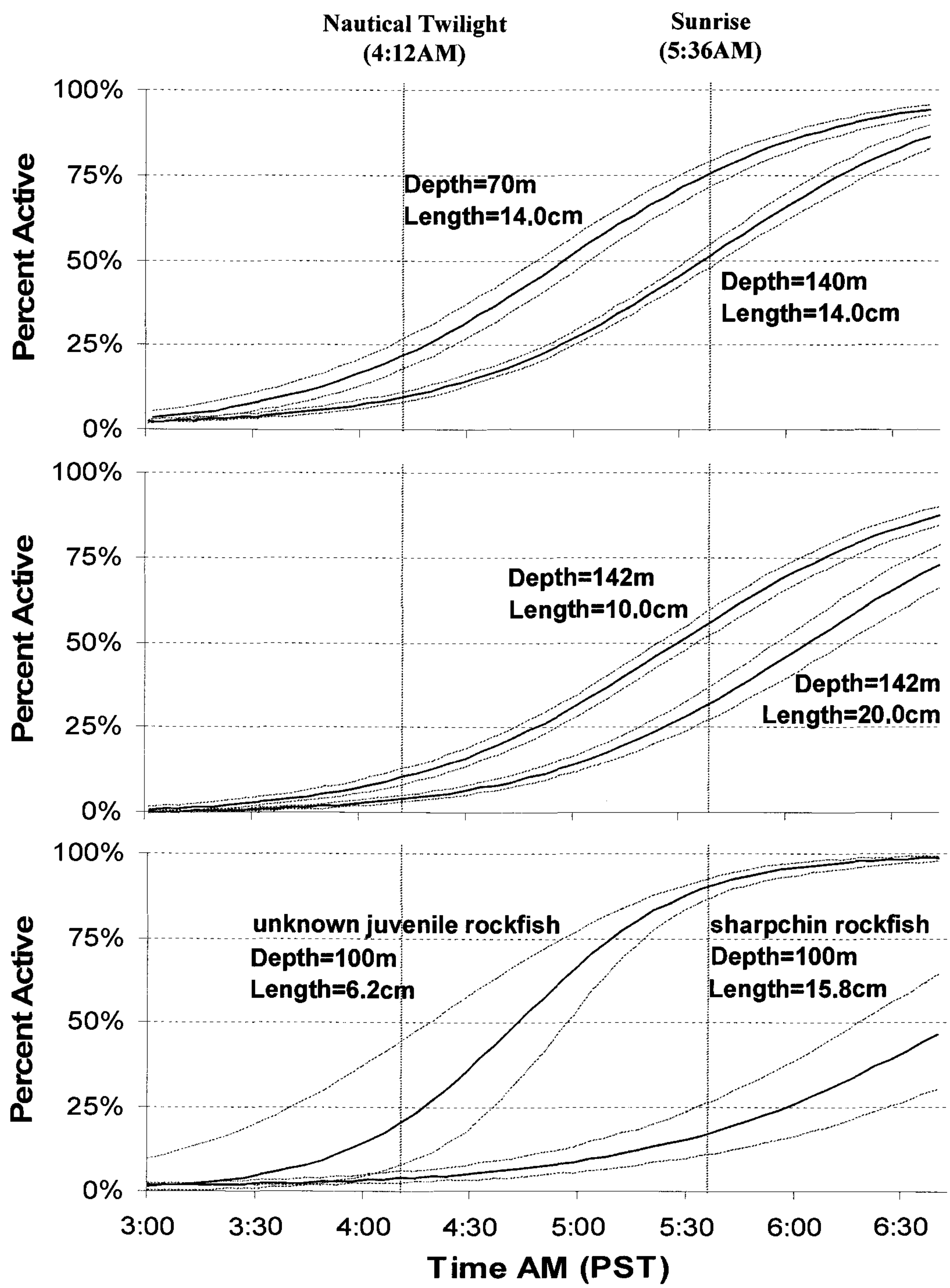

Nautical Twilight
(4:12AM)
Sunrise
(5:36AM)
100%
75%
50%
25%
0%
Percent Active
Depth=70m
Length=14.0cm
Depth=140m
Length=14.0cm
Depth=142m
Length=10.0cm
Depth=142m
Length=20.0cm
unknown juvenile rockfish
Depth=100m
Length=6.2cm
sharpchin rockfish
Depth=100m
Length=15.8cm
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
Time AM (PST)

Figure 2.5.

Table 2.1: Location, depth, most dominant primary habitat, area surveyed, and total transect distance during morning (3:00am to 6:30am) and evening (6:00pm to 12:30am) surveys.

	Morning	Evening
Stations:	Night: 2, 3, 4, and 9 Dawn: 3, 4, and 9	Day: 1, 2, 3, 4, 6, and 9 Dusk: 8 and 10 Night: 2, 8, 9, and 10
Depth:	Night: 101-200 m (mean 149 m) Dawn: 70-180 m (mean 129 m)	Day: 68-174 m (mean 135 m) Dusk: 195-243 m (mean 213 m) Night: 114-285 m (mean 183 m)
Primary Habitat:	Night: Cobble, Boulder Dawn: Rock ridge, Cobble	Day: Cobble, Rock ridge Dusk: Mud, Cobble Night: Boulder, Cobble
Area (hectares):	Night: 0.46 Dawn: 0.53	Day: 1.14 Dusk: 0.32 Night: 0.83
Transect Length (km):	Night: 2.91 Dawn: 3.46	Day: 8.16 Dusk: 2.68 Night: 7.13

Table 2.2: Logistic regression of activity using binomial data (active or inactive) during morning (3:00am to 6:30am, N=4,091) and evening (6:00pm to 12:30am, N=10,540) periods.

	Morning	Evening
Logistic Regression Coefficients:		
Time	20.6 (p-value < 0.0001)	-16.9 (p-value < 0.0001)
Fish depth	-11.5 (p-value < 0.0001)	-32.4 (p-value < 0.0001)
Fish length	-7.6 (p-value < 0.0001)	-19.1 (p-value < 0.0001)
Percent of deviance explained by model	46.0%	71.4%

Table 2.3: Number of fish per hectare during the morning period (3:00am to 6:30am) consisting of night and dawn and the evening period (6:00pm to 12:30am) consisting of day, dusk, and night periods.

Taxon	Species	No. of individuals / hectare				
		Night	Dawn	Day	Dusk	Night
Crepuscular Predators:						
yellowtail rockfish	*Sebastes flavidus*	361	414	122	0	8
yelloweye rockfish	*Sebastes ruberrimus*	0	0	2	116	23
canary rockfish	*Sebastes pinniger*	19	6	5	0	3
widow rockfish	*Sebastes entomelas*	15	4	2	0	1
lingcod	*Ophiodon elongatus*	23	19	6	0	6
Other Taxa:						
sharpchin rockfish	*Sebastes zacentrus*	2811	1188	413	211	1900
pygmy rockfish	*Sebastes wilsoni*	0	184	3247	0	3
unknown adult rockfish	*Sebastes sp.*	888	991	266	47	83
unknown juvenile rockfish	*Sebastes sp.*	15	1002	764	0	1
pygmy-Puget Sound complex	*Sebastes wilsoni and emphaeus*	2	25	1349	0	0
rosethorn rockfish	*Sebastes helvomaculatus*	128	340	262	13	53
greenstriped rockfish	*Sebastes elongatus*	216	116	91	19	108
Puget Sound rockfish	*Sebastes emphaeus*	4	72	400	0	14
Harlequin rockfish	*Sebastes variegatus*	118	2	0	0	4
darkblotched rockfish	*Sebastes crameri*	0	2	1	85	7
redstripe rockfish	*Sebastes proriger*	10	36	1	0	0
shortspine thornyhead	*Sebastolobus alascanus*	0	0	0	0	31
kelp greenling	*Hexagrammos decagrammus*	0	9	4	0	0
unknown ronquil	*Rathbunella sp.*	0	0	11	3	5
unknown mottled sculpin	*Cottidae sp.*	10	15	20	13	13
unknown sculpin	*Cottidae sp.*	2	6	8	0	4
threadfin sculpin	*Icelinus filamentosus*	23	6	10	31	13
unknown Icelinus sculpin	*Icelinus sp.*	2	0	9	6	1
unknown mottled poacher	*Agonidae sp.*	4	4	9	182	31
bigfin eelpout	*Lycodes cortezianus*	0	0	2	116	23
spotted ratfish	*Hydrolagus colliei*	0	13	0	0	0
unknown hagfish	*Eptatretus sp.*	0	25	0	38	0
unknown fish	unknown fish	4	32	9	25	11
	Total no. of individuals/hectare	4656	4510	7014	905	2348
	Total no. of dives	4	4	6	2	4

GENERAL CONCLUSION

This study represents the first investigation of diel activity, distribution, and abundance of demersal fish over a large, relatively deep rocky bank on the North American west coast. The marked differences in abundance between day and night periods for dominant fish taxa, over paired transects in specific habitats and depths, and the changeover in dominant taxa from day to night suggests that diel niche partitioning for habitat and prey occurs. Evidence of sequential emergence and a possible earlier quiet period suggests twilight activity patterns are still selected for, possibly cued by changes in light intensity and possibly formed by relaxation in predation pressure. The consistency of most of these trends with abundance patterns found in the submersible diel investigation on the shallow Stonewall Bank (Hixon and Tissot, 1992) and activity patterns observed in other temperate diel studies (Ebeling and Bray, 1976; Hobson et al., 1981; Moulton, 1977) suggests that circadian rhythm behavior may be cued by light. However, the fact that most fish taxa did not exhibit any marked differences in diel activity or distribution suggests that such behavior is not selected for to the degree that it is in shallow, temperate rocky reefs, or even to the extent it is on tropical reefs.

This study suggests that strictly daytime groundfish trawl surveys over small- to medium-size substrata present a significant sampling bias for some demersal fishes. Specifically, Puget Sound rockfish may be more available, while other dominant day taxa (pygmy rockfish, pygmy-Puget Sound rockfish, and unknown juvenile rockfish over shallow, large-size substrata) and sharpchin rockfish are likely less available to trawl surveys. The fact that diel fish activity may affect the availability of some fishes to ROV (Remotely Operated Vehicle) and trawl surveys off the Oregon coast underscores the importance of considering diel activity patterns when conducting demersal fish surveys. This evidence suggests that regulating times of fishing effort in an attempt to avoid species of concern may be a useful management tool.

It is recommended that further studies utilize the wealth of trawl data along the West Coast to examine diel differences in abundance and distribution. Such a study could overlay this data with recently developed West Coast habitat maps to determine any long term trends in abundance and distribution at various habitat-depth profiles that this study was not able to address.

APPENDIX

APPENDIX A

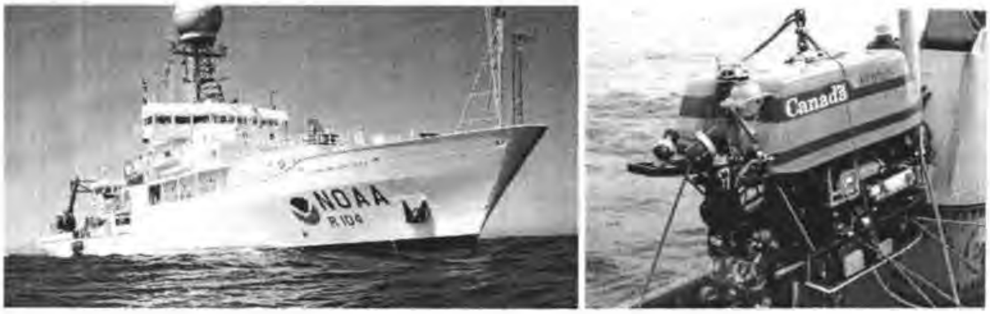


Figure A. *R/V Ronald H. Brown* and Canadian *ROPOS* ROV.

APPENDIX B

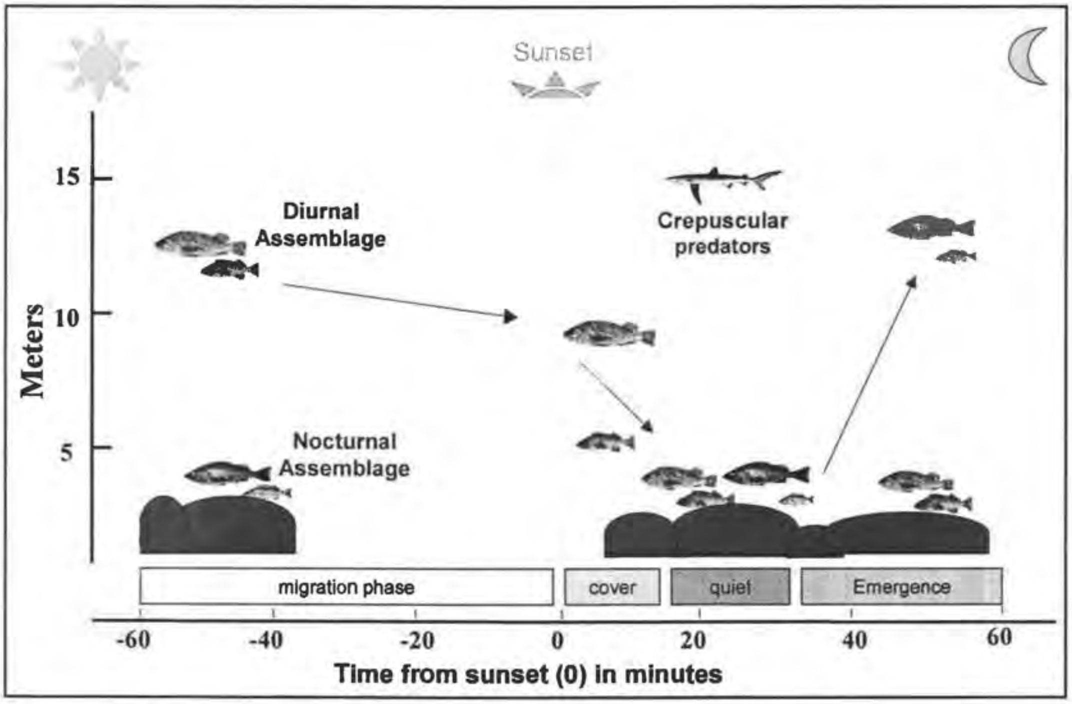


Figure B. Diel movements of fishes on shallow subtropical rocky banks and tropical reefs with time relative to sunset in minutes (Modified Helfman figure, Helfman, G. S., B. B. Collette, and D. E. Facey. 1997. The Diversity of Fishes. Blackwell Science Inc. 528 pp.)

APPENDIX C

Table C. Summary of 2000 Heceta Bank ROPOS survey. Surveys occurred during day and night in all stations except for stations 1 and 8. Surveys only occurred during dawn and dusk periods in stations 3, 4, and 9, and 3, 8, and 10 respectively. Date and time are in daylight savings PST (Pacific Standard Time). Time periods determining day, night, dawn, and dusk periods were derived using the U.S. Naval Observatory.

Station	Dive	Tran	Date (PST)	Fish transect time frame (PST)	Total Time	Diel Period	Day time	Day dist.	Night time	Night dist.	Dawn time	Dawn dist.	Dusk time	Dusk dist.
4	527	1	18-Jun	2:45:50 AM - 3:46:11 AM	1:00:21	Night			1:00:21	0.8				
		2	18-Jun	6:08:18AM - 6:29:47AM	0:21:29	Dawn					0:21:10			
4	526	1	19-Jun	2:32:55 PM - 4:48:51 PM	2:15:56	Day	2:15:56	3.02						
		2	19-Jun	5:51:14 PM - 8:04:17 PM	3:02:36	Day	3:02:36	2.37						
		3	20-Jun	2:55:19 AM - 3:40:00 AM	0:44:41	Night			0:44:41	0.7				
		4	20-Jun	5:03:15 AM - 5:47:16 AM	0:44:01	Dawn					0:44:01	0.8		
1	529	1	19-Jun	1:46:46 PM-7:23:28 PM	4:54:42	Day	4:54:42	7.12						
2	531	1	21-Jun	1:06:01 PM - 4:01:00 PM	2:54:59	Day	2:54:59	2.31						
		2	21-Jun	4:50:24 PM - 7:43:00 PM	2:52:36	Day	2:52:36	2.37						
		3	21-Jun	10:08:16 PM - 12:45:55 AM	2:37:39	Night			2:37:39	2.3				
		4	22-Jun	1:38:20 AM - 4:10:46 AM	2:32:26	Night			2:32:26	2.3				
3	532	1	22-Jun	4:00:45 PM - 5:57:26 PM	1:56:41	Day	1:56:41	2.53						
		2	22-Jun	6:27:32 PM - 8:31:59 PM	2:04:27	Day-Dusk	2:04:27	1.96					0:24:59	0.4
	533	1	23-Jun	1:35:45 AM - 3:32:13 AM	1:56:28	Night			1:56:28	2.3				
		2	23-Jun	4:12:04 AM - 6:02:59 AM	0:21:58	Night-Dawn			0:21:58	0.5	1:26:59	1.8		
6	534	1	23-Jun	12:43:20 PM - 2:40:10 PM	1:56:50	Day	1:56:50	2.42						
		2	23-Jun	4:47:29 PM - 6:45:10 PM	1:57:41	Day	1:57:41	2.19						
6	535	1	24-Jun	12:23:26 AM - 3:04:56 AM	2:41:30	Night			2:41:30	2.6				
8	536	1	24-Jun	8:51:33 PM - 11:30:00 PM	1:21:56	Dusk-Night			1:21:56	1.9			1:15:41	0.6
		2	25-Jun	12:51:53 AM - 2:03:31 AM	1:11:38	Night			1:11:38	1.1				
9	537	1	25-Jun	4:22:33 PM - 6:29:33 PM	2:07:00	Day	2:07:00	2.55						
9	538	1	June 25-26	11:17:04 PM - 2:34:04 AM	3:17:00	Night			3:17:00	2.4				
		2	26-Jun	2:52:40 AM - 5:02:00 AM	1:49:52	Night-Dawn			1:49:52	2.2	0:19:28	0.4		
10	539	1	26-Jun	11:23:52 AM - 1:59:06 PM	2:35:14	Day	2:35:14	2.57						
		2	26-Jun	2:35:54 PM - 5:00:15 PM	2:24:21	Day	2:24:21	3.58						
		3	26-Jun	9:05:12 PM - 11:25:40 PM	2:20:28	Dusk-Night			0:54:31	0.9			1:25:57	1.7
		4	June 26-27	11:32:57 PM - 1:08:06 AM	1:35:09	Night			1:35:09	1.5				
				Total Time(hrs)=	59:06:27	Time (PST)	31:03:03		22:05:09		2:51:38		3:06:37	
				Total distance (km) =	62.2	Distance		35.0		21.5		3.0		2.7

APPENDIX D

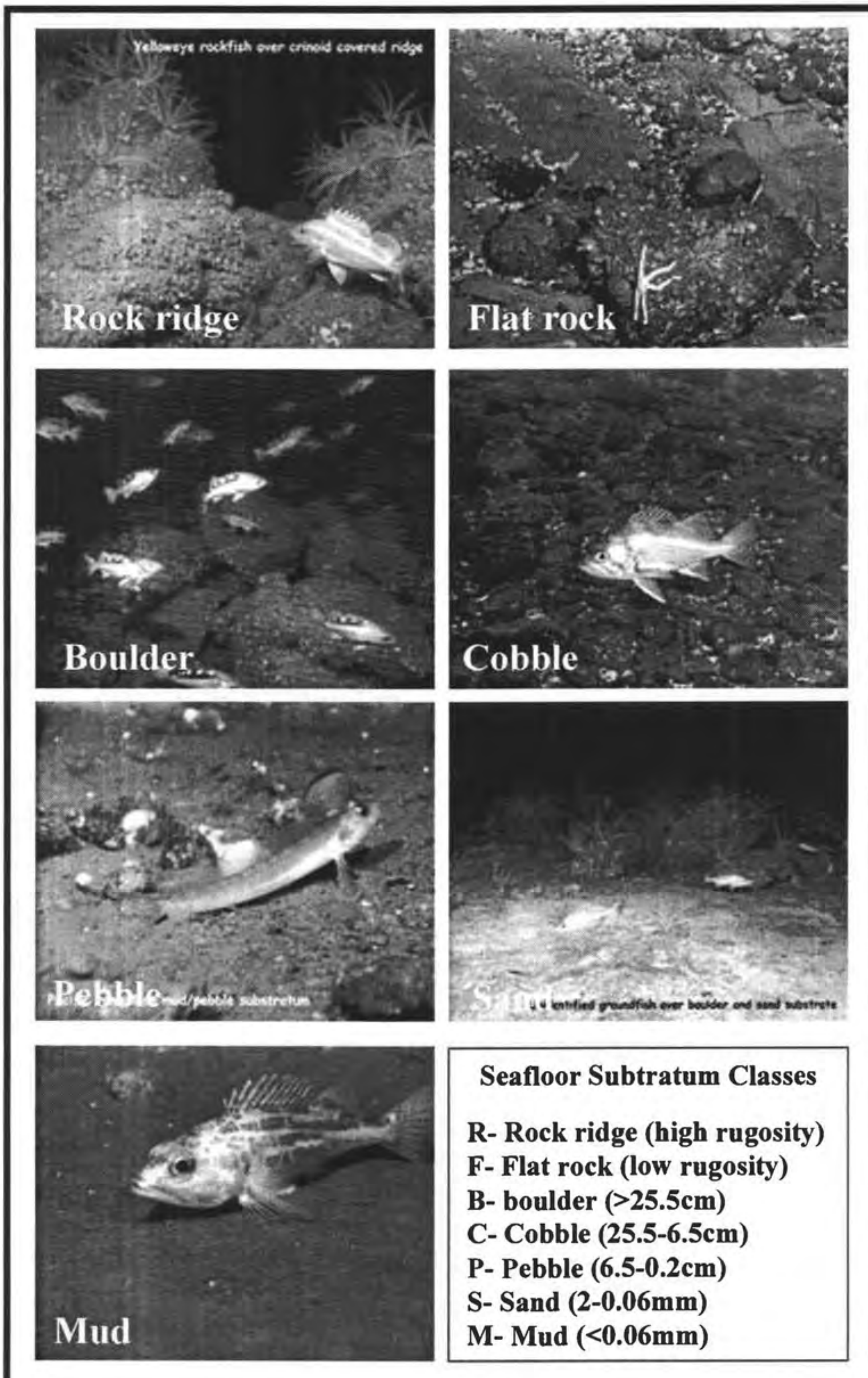


Figure D. Habitat Classification.

APPENDIX E

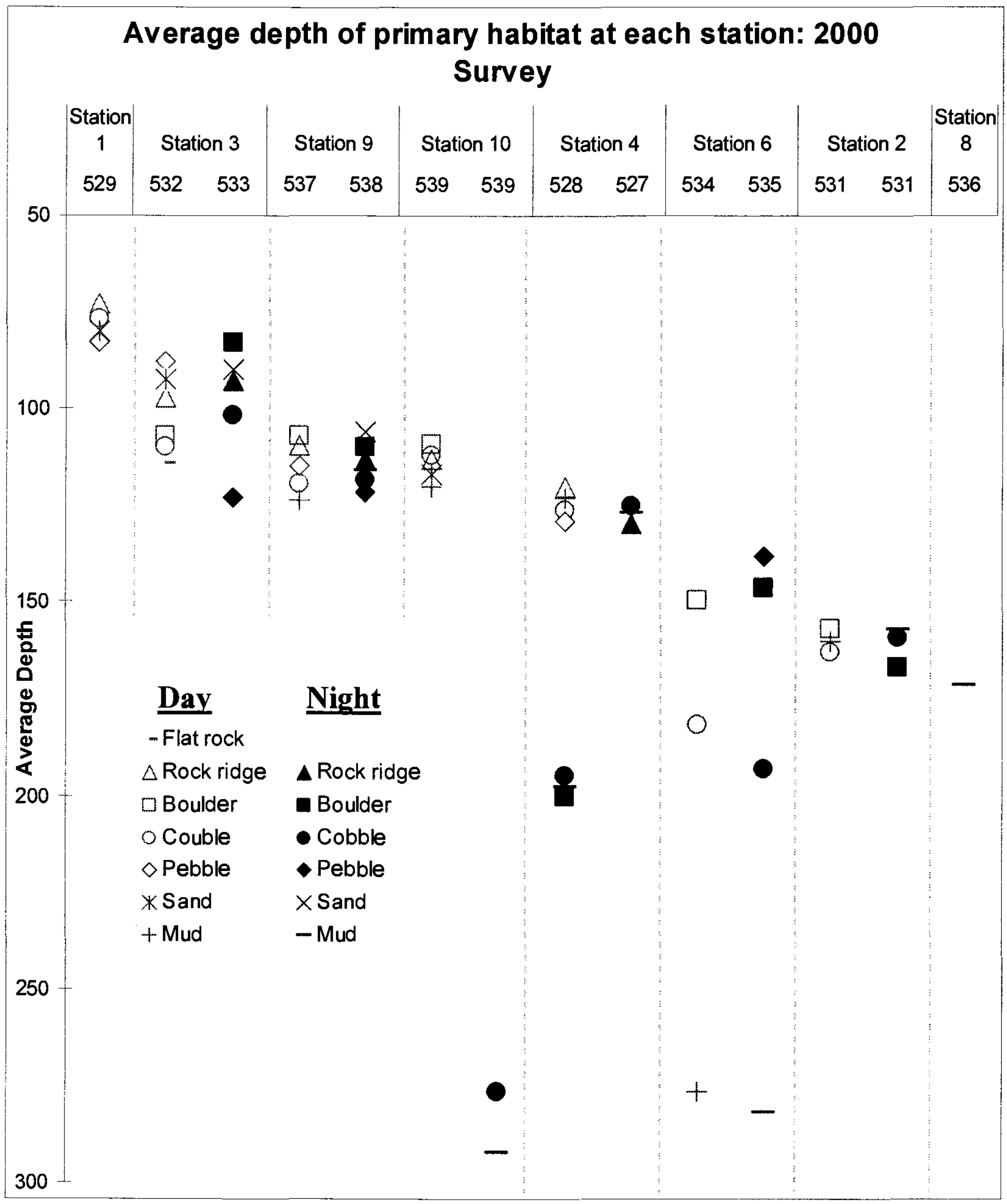


Figure E. Average depth of primary habitat at each station. Dives listed in order of increasing depth from left to right.

APPENDIX F

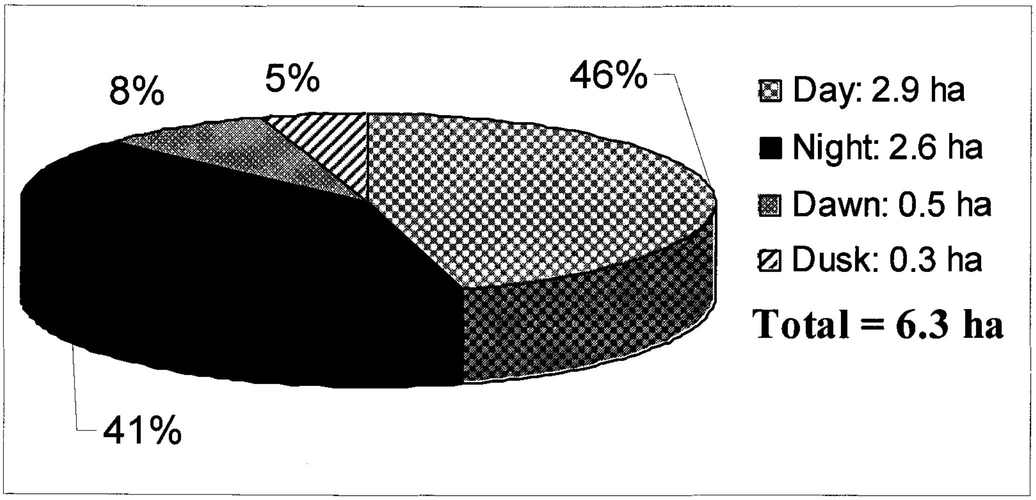


Figure F1. Area in hectares and percent covered during day, night, dawn, and dusk during the 2000 ROPOS survey within stations 2, 3, 4, 6, and 9.

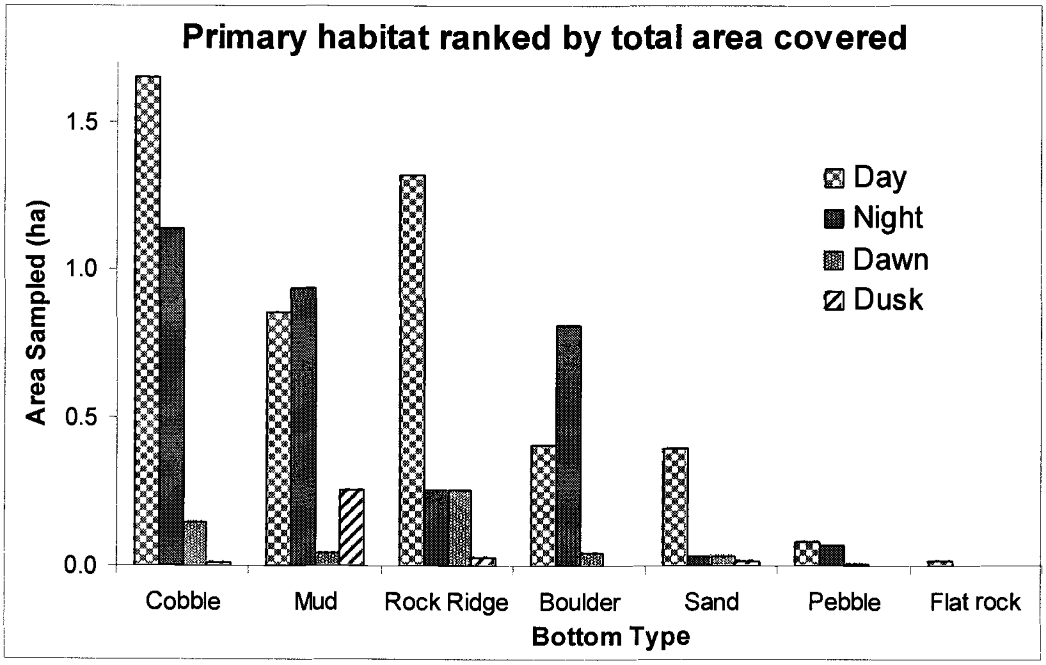


Figure F2. Area in hectares of primary habitat surveyed during the 2000 ROPOS survey within stations 2, 3, 4, 6, and 9.

APPENDIX G

Table G. Abundance of 50 fish taxa encountered during the 2000 ROPOS survey ranked in order of total abundance per hectare.

Common Name	Taxonomic Name	Day Abundance/ha	Night Abundance/ha	Total	% total abunance
sharpchin rockfish	*Sebastes zacentrus*	423.2	2993.0	3416.2	31.44%
unknown juvenile rockfish	*Sebastes sp.*	1366.2	70.8	1437.0	13.22%
Puget Sound rockfish	*Sebastes emphaeus*	1253.0	19.2	1272.3	11.71%
pygmy rockfish	*Sebastes wilsoni*	1264.6	6.9	1271.5	11.70%
pygmy-Puget Sound complex	*S. wilsoni and emphaeus*	846.3	28.5	874.8	8.05%
unknown adult rockfish	*Sebastes sp.*	349.1	425.4	774.5	7.13%
rosethorn rockfish	*Sebastes helvomaculatus*	308.6	117.0	425.7	3.92%
yellowtail rockfish	*Sebastes flavidus*	204.2	147.4	351.7	3.24%
Dover Sole	*Microstomus pacificus*	60.1	122.0	182.1	1.68%
greenstriped rockfish	*Sebastes elongatus*	69.5	100.5	170.0	1.56%
redstripe rockfish	*Sebastes proriger*	64.9	50.4	115.4	1.06%
unknown hagfish	*Eptatretus sp.*	17.5	39.3	56.7	0.52%
spotted ratfish	*Hydrolagus colliei*	9.4	46.6	56.0	0.52%
harlequin rockfish	*Sebastes variegatus*	0.0	47.0	47.0	0.43%
sablefish	*Anoplopoma fimbria*	2.8	30.0	32.8	0.30%
widow rockfish	*Sebastes entomelas*	3.8	27.7	31.6	0.29%
unknown poacher	*unknown agonidae*	24.1	6.2	30.2	0.28%
unknown mottled sculpin	*unknown*	22.7	6.5	29.2	0.27%
lingcod	*Ophiodon elongatus*	15.4	10.8	26.1	0.24%
unknown ronquil	*Rathbunella sp.*	24.1	1.9	26.0	0.24%
unknown small flatfish	*unknown*	11.2	13.1	24.3	0.22%
yelloweye rockfish	*Sebastes ruberrimus*	13.3	8.9	22.1	0.20%
unknown flatfish	*unknown*	6.6	14.6	21.3	0.20%
canary rockfish	*Sebastes pinniger*	10.1	10.0	20.1	0.19%
rex sole	*Glyptocephalus zachirus*	4.9	13.1	18.0	0.17%
threadfin sculpin	*Icelinus filamentosus*	8.0	9.6	17.7	0.16%
unknown fish	*unknown*	13.6	3.5	17.1	0.16%
unknown sculpin	*unknown*	14.3	2.7	17.0	0.16%
unknown Icelinus sculpin	*Icelinus sp.*	9.8	3.5	13.2	0.12%
shortspine thornyhead	*Sebastolobus alascanus*	11.2	1.5	12.7	0.12%
unknown eelpout	*Lycodapus sp.*	5.9	1.9	7.9	0.07%
spotted cusk-eel	*Chilara taylori*	0.0	7.3	7.3	0.07%
bigfin eelpout	*Lycodes cortezianus*	3.8	2.3	6.2	0.06%
kelp greenling	*Hexagrammos decagrammus*	4.5	0.4	4.9	0.05%
Pacific hake	*Merluccius productus*	0.0	3.8	3.8	0.04%
darkblotched rockfish	*Sebastes crameri*	0.3	3.5	3.8	0.04%
unknown skate	*Raja sp.*	2.1	1.2	3.2	0.03%
unknown poacher	*unknown*	3.1	0.0	3.1	0.03%
longnose skate	*Raja rhina*	1.4	1.5	2.9	0.03%
big skate	*Raja binoculata*	0.0	2.3	2.3	0.02%
unknown adult rockfish	*Sebastes sp.*	2.1	0.0	2.1	0.02%
tiger rockfish	*Sebastes nigrocinctus*	0.3	1.5	1.9	0.02%
sturgeon poacher	*Agonus acipenserinus*	1.7	0.0	1.7	0.02%
slender sole	*Lyopsetta exilis*	1.4	0.0	1.4	0.01%
greenspotted rockfish	*Sebastes chlorostictus*	1.4	0.0	1.4	0.01%
Pacific halibut	*Hipoglossus stenolepis*	0.3	0.4	0.7	0.01%
Pacific cod	*Gadus macrocephalus*	0.0	0.4	0.4	0.00%
bocaccio	*Sebastes paucispinis*	0.0	0.4	0.4	0.00%
brown rockfish	*Sebastes auriculatus*	0.0	0.4	0.4	0.00%
unknown prickleback	*unknown*	0.3	0.0	0.3	0.00%
	Total	**6461.4**	**4405.0**	**10866.4**	100.00%

APPENDIX H

Figure H1: Day Assemblage.

Illustration of the 5 most dominant fish taxa during the day over 3 depth-habitat profiles. Abundance (number of fish / hectare) is shown by 1 fish < 10 fish/ha, 2 fish = 10-100 fish/ha, 3 fish = 100-1,000 fish/ha, and 4 fish >1,000 fish/ha. Fish off bottom represent taxa with significantly greater percent of individuals more active. Fish in contact with the seafloor denote taxa with significantly greater percent of individuals inactive. Fish taxa in parentheses were significantly more abundant, but did not show significantly greater activity during day or night.

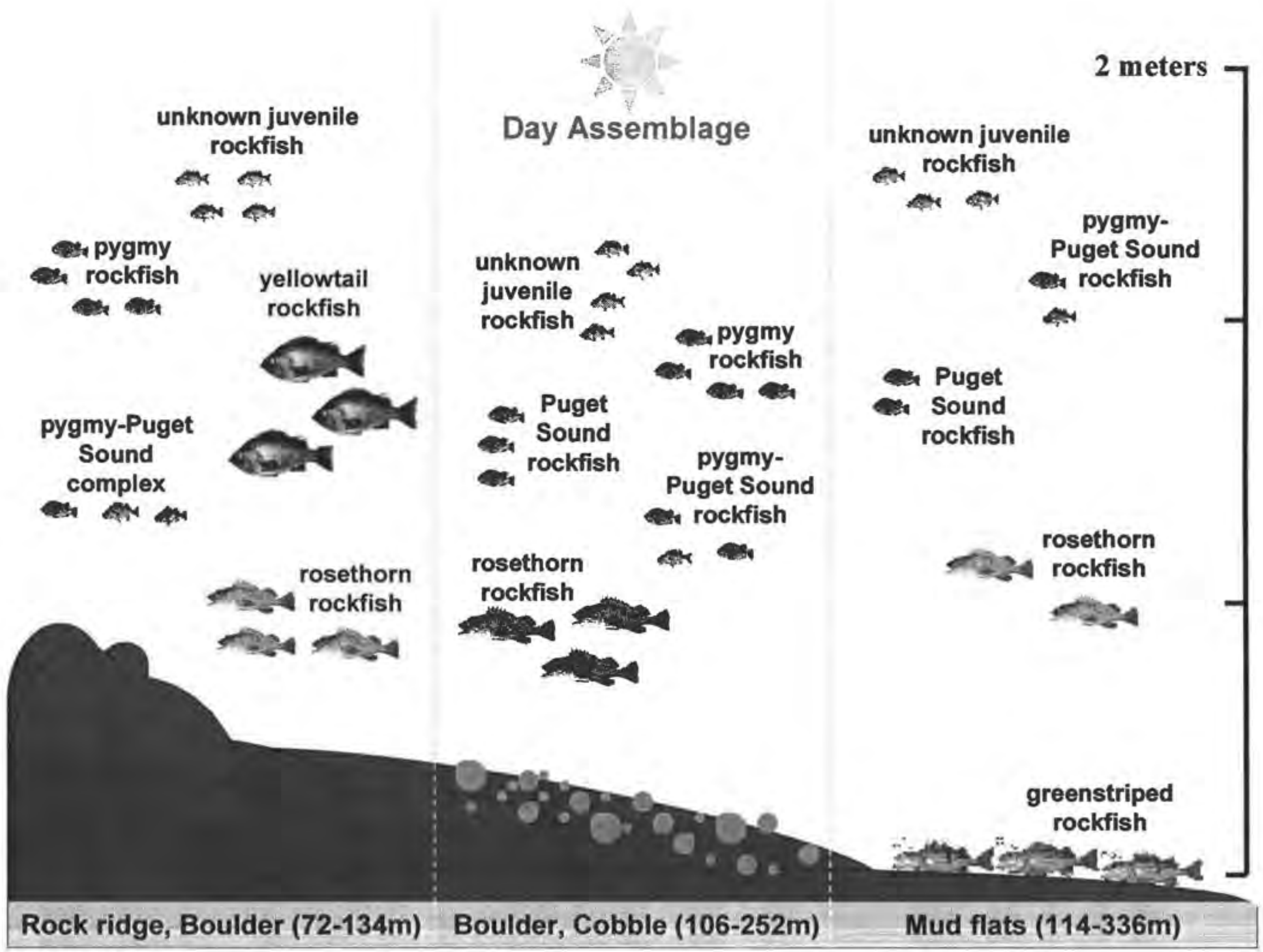

Day Assemblage
2 meters
unknown juvenile rockfish
pygmy rockfish
yellowtail rockfish
pygmy-Puget Sound complex
rosethorn rockfish
unknown juvenile rockfish
pygmy rockfish
Puget Sound rockfish
pygmy-Puget Sound rockfish
rosethorn rockfish
unknown juvenile rockfish
pygmy-Puget Sound rockfish
Puget Sound rockfish
rosethorn rockfish
greenstriped rockfish
Rock ridge, Boulder (72-134m)
Boulder, Cobble (106-252m)
Mud flats (114-336m)

Figure H1.

Figure H2. Night Assemblage.

Illustration of the 5 most dominant fish taxa during the night over 3 depth-habitat profiles. Abundance (number of fish / hectare) is shown by 1 fish < 10 fish/ha, 2 fish = 10-100 fish/ha, 3 fish = 100-1,000 fish/ha, and 4 fish >1,000 fish/ha. Fish off bottom represent taxa with significantly greater percent of individuals more active. Fish in contact with the seafloor denote taxa with significantly greater percent of individuals inactive. Fish taxa in parentheses were significantly more abundant, but did not show significantly greater activity during day or night.

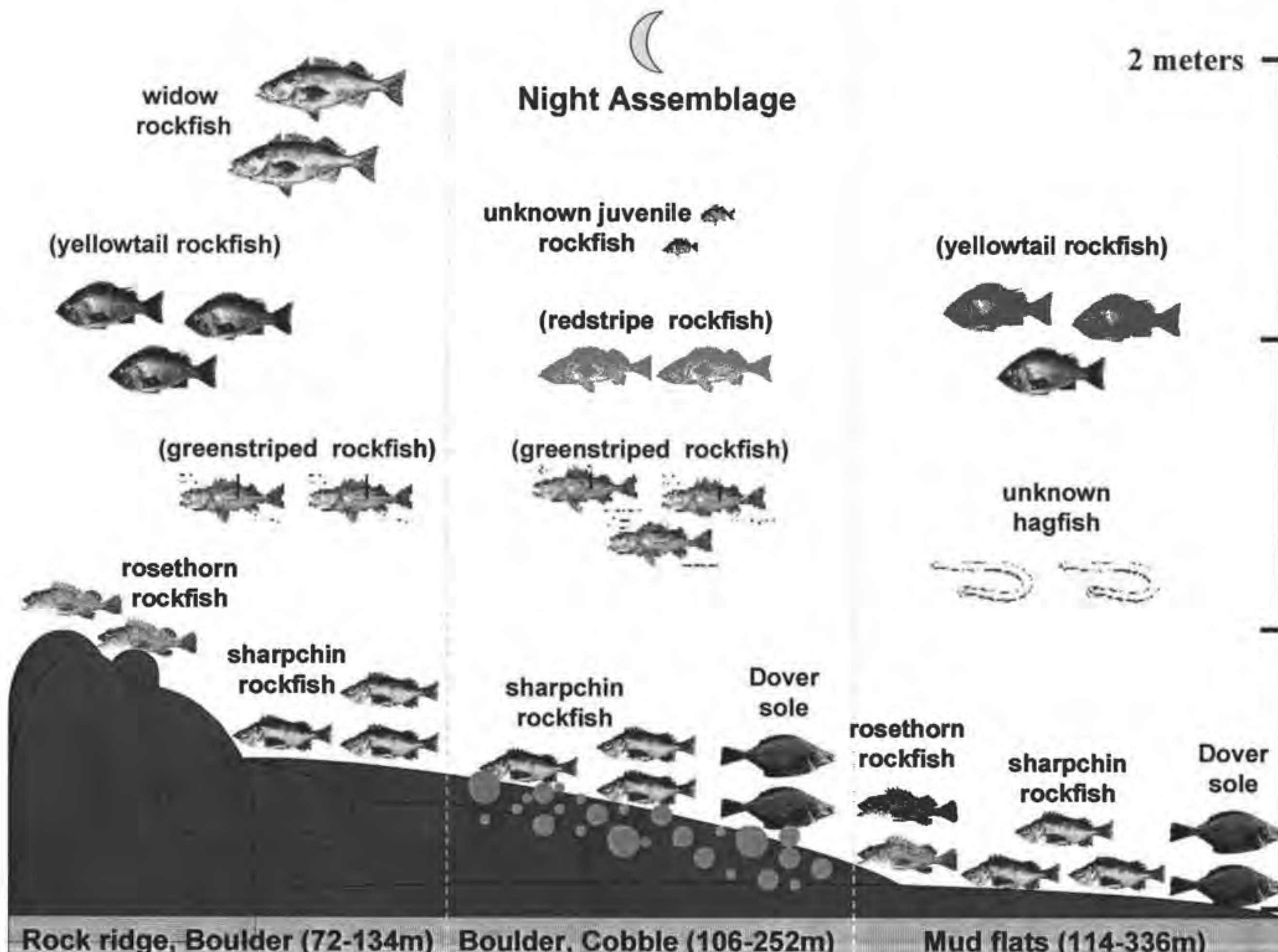

Night Assemblage
2 meters
widow rockfish
(yellowtail rockfish)
unknown juvenile rockfish
(yellowtail rockfish)
(redstripe rockfish)
(greenstriped rockfish)
(greenstriped rockfish)
unknown hagfish
rosethorn rockfish
sharpchin rockfish
sharpchin rockfish
Dover sole
rosethorn rockfish
sharpchin rockfish
Dover sole
Rock ridge, Boulder (72-134m)
Boulder, Cobble (106-252m)
Mud flats (114-336m)

Figure H2.

APPENDIX I

Table I1: Literature review of the affects of different video survey methods on the behavior of fishes.

Sampling device	Fish Behavior	Location	Reference
ROPOS ROV	Majority of fish did not show any response. Yellowtail and canary rockfish followed ROV and actively fed on organisms stirred up by propeller action and umbilical cord scraping the seafloor.	Heceta Bank	Wakefield and Parker 2001
Submersible *Delta*	Most fish showed no change in behavior. Yellowtail rockfish were attracted to and followed the submersible when stationary and moving for periods in excess of an hour.	Heceta Bank	Pearcy et al. 1989
Submersible *Delta*	No change in fish behavior between submersible surveys and sitting on seafloor powered down.	Heceta Bank	Hixon et al. 1991 & 1992, Stein et al. 1992
Submersible *Makalii*	Some changes in fish behavior.	Johnston Atoll in Central Pacific	Ralston et al. 1986
Submersible *Nekton Gamma*	Most rockfish were not repelled by or attracted to the submersible. Yelloweye rockfish were attracted, lingcod slightly attracted, and halibut acted curious but cautious towards the submersible.	Southeastern Alaska	Carlson and Straty 1981
Submersible *Nekton Gamma*	No fish were frightened, but halibut followed the submersible on occasion.	Alaska	High 1980
Submersible *Nekton Gamma, camera sled, and trawl*	Most fish showed no change in behavior. Possible photonegative response to video techniques from squids, herring, mackerel, and butterfish.	Georges Bank	Uzmann et al. 1977
Submersible	Majority of fish did not show any response. Some fishes followed and actively fed on organisms stirred up by propeller action.	Gulf of California	Hobson 1965
Camera Sled and submersible Alvin	No change in behavior between surveys with different sampling devices.	Slope of Central California	Wakefield and Smith 1990
SCUBA	Neither attraction nor avoidance of divers was observed within field of view (7.5m).	Southeastern United States	Powles and Barans 1980
SCUBA	Dive lights may have attracted or repelled fish depending on species, but the brief exposure to light did not seem to affect fishes normal behavior.	Santa Barbara kelp forests, California	Ebeling and Bray 1976
SCUBA	Some diurnal and nocturnal fishes were immobilized by flashlight during night surveys.	Gulf of California	Hobson 1965
SCUBA and Snorkeling	During night, some fishes exhibited pronounced response to diving (bubbles) compared to snorkeling. During the day, there were no noticeable differences in response to the two methods.	Gulf of California	Hobson and Chess 1976

Table I2: References of literature review of the affects of different video survey methods on the behavior of fishes.

Carlson, H. R., and R. R. Straty.
1981. Habitat and nursery grounds of Pacific rockfish, *Sebastes spp.*, in rocky coastal areas of southeastern Alaska. Mar. Fish. Rev. 43(7):13-19.

Ebeling, A. W., and R.N. Bray.
1976. Day versus night activity of reef fishes in a kelp forest off Santa Barbara, California. Fish. Bull. 74:703-717.

High, W. L.
1980. Bait loss from halibut longline gear observed from a submersible. Mar. Fish. Rev. 42(2):26-29.

Hixon, M. A., B.N. Tissot, and W. G. Pearcy.
1991. Fish assemblages of rocky banks of the Pacific Northwest [Heceta, Coquille, and Daisy Banks]. OCS Study MMS 91-0052, USDI Minerals Management Service, OCS Study MMS 91-0052, Camarillo, CA. 195pp.

Hixon, M. A., and B. N. Tissot.
1992. Fish assemblages of rocky banks of the Pacific Northwest [Stonewall Bank]. OCS Study MMS 92-0025, USDI Minerals Management Service, OCS Study, Camarillo, CA. 128pp.

Hobson, E. S.
1965. Diurnal-nocturnal activity of some inshore fishes in the Gulf of California, Copiea, 3:291-302.

Hobson, E. S, and J. R. Chess.
1976. Trophic interactions among fishes and zooplankters nearshore at Santa Catalina Island. Cal. Fish. Bull. 4(3):567-598.

Pearcy, W. G., D. L. Stein, M. A. Hixon, E. K. Pikitch, W. H. Barss, and R. M. Starr.
1989. Submersible observations of deep-reef fishes of Heceta Bank, Oregon. Fish. Bull. 87:955-965.

Powles, H, and C. A. Barans.
1980. Groundfish monitoring in sponge-coral area off the southeastern United States. Mar. Fish. Rev. 42(5):21-35.

Ralston, S., R. M. Gooding, and G. M. Ludwig.
1986. An ecological survey and comparison of bottom fish resource assessments (submersible) versus handline fishing at Johnston atoll. Fish. Bull. 84(1):141-155.

Table I2: (Continued)

Stein, D. L., B. N. Tissot, M. A. Hixon, and W. Barss.
1992. Fish-habitat associations on a deep reef at the edge of the Oregon continental shelf. Fish. Bull. 90:540-551.

Uzmann, J. R., R. A. Cooper, R. B. Theroux, and R. L. Wigley.
1977. Synoptic comparison of three sampling techniques for estimating abundance and distribution of selected mega-fauna: Submersible vs. camera sled vs. otter trawl. Mar. Fish. Rev. 39(12):11-19.

Wakefield, W. W., and K. L. Smith, Jr.
1990. Ontogenetic vertical migration in *Sebastolobus altivelis* as a mechanism for transport of particulate organic matter at continental slope depths. Limnol. Oceanogr. 35(6):1314-1328.

Wakefield, W. W., and Parker, SJ.
2001. 'View from the rear view mirror of an ROV', Presentation from 13th Western Groundfish Conference.