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Pupping phenology, disturbance, movements, and dive patterns of the harbor seal (Phoca vitulina richardsi) off the northern San Juan Islands of Washington

Robert M. Suryan
San Jose State University

PUPPING PHENOLOGY, DISTURBANCE, MOVEMENTS, AND DIVE PATTERNS OF THE HARBOR SEAL (*Phoca vitulina richardsi*) OFF THE NORTHERN SAN JUAN ISLANDS OF WASHINGTON

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Robert M. Suryan

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APPROVED FOR THE DEPARTMENT OF MARINE SCIENCE

Dr. James T. Harvey, Assistant Professor, Committee Chair

Dr. Robert L. DeLong, Wildlife Research Biologist

Dr. Michael S. Foster, Professor

APPROVED FOR THE UNIVERSITY

ABSTRACT

PUPPING PHENOLOGY, DISTURBANCE, MOVEMENTS, AND DIVE PATTERNS OF THE HARBOR SEAL (*Phoca vitulina richardsi*) OFF THE NORTHERN SAN JUAN ISLANDS OF WASHINGTON

by Robert M. Suryan

Observations of three haul-out sites and radio telemetry were used to study pupping phenology, disturbance, movements, and dive patterns of harbor seals off the northern San Juan Islands, Washington. Most pupping occurred in late June and early July, with maximum numbers of pups ashore the last week in July and first week in August. Harassments of harbor seals were common (> 71% of survey days), primarily caused by powerboaters (42 to 76% of harassments; n = 94) approaching within a mean distance of 129 m from seals at Puffin Island and 154 m at Clements Reef. Haul-out site fidelity ranged from 33% to 100%. Foraging areas, located within 4 km of the primary haul-out sites, were characterized by a shoaling seafloor and strong rip currents. Mean duration of dive was significantly ($p < 0.05$) greater for harbor seals during milling (presumably foraging; 4.00 to 6.22 min) than traveling (3.16 to 3.57 min), resting (2.88 min), and nearshore activities (1.52 to 3.59 min).

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INTRODUCTION

Harbor seals (*Phoca vitulina*) are common in coastal regions of the North Atlantic and North Pacific Oceans. *Phoca vitulina richardsi* inhabits the eastern North Pacific from Isla San Martin in Baja California, Mexico, to the Pribilof and Aleutian Islands of Alaska (Scheffer 1967, Scheffer 1974, Shaughnessy and Fay 1977, King 1983, Temte 1985). Local movements (< 25 km) of harbor seals have been documented (Brown and Mate 1983, Jeffries 1986, Harvey 1987, Stein 1989, Thompson 1989); however, this species is considered non-migratory (Bigg 1981).

The abundance of harbor seals in proximity to nearshore fisheries has resulted in conflicts with commercial and sport fishery operations (Ilmer and Saber 1947, Fisher 1952, Spalding 1964, Mate 1980, Beach et al. 1985, Harvey 1989). These conflicts resulted in control programs early in the 1900's to reduce populations throughout much of the northeast Pacific (Olesiuk et al. 1990). With protection of harbor seals in British Columbia (B.C.; 1970) and the United States (1972), populations in most areas have increased (Calambokidis et al. 1985, Brown 1986, Jeffries 1986, Boveng 1988, Harvey et al. 1990), although declines in number of harbor seals have been reported for the Bering Sea, Aleutian Islands (National Marine Fisheries Service and Alaska Department of Fish and Game unpubl. data), and Gulf of Alaska (Pitcher 1989, Pitcher 1990).

The harbor seal is the most common and abundant marine mammal in Washington state (Jeffries and Johnson 1987), and the only pinniped that breeds in the state (Everitt et al. 1980). Greatest statewide counts of harbor seals ashore during 1992 surveys were 22,100 animals, of which 3679 (16.6%) were off the San Juan Islands (Huber et al. 1992).

Harbor seals use specific haul-out sites throughout the year, and are an ideal indicator of short and long term environmental disturbances in local areas (Everitt et al. 1980).

The purpose of this project was to study the pupping phenology (Chapter 1), disturbance (Chapter 2), movements and dive patterns (Chapter 3) of harbor seals off the northern San Juan Islands, Washington.

CHAPTER 1

PUPPING PHENOLOGY

INTRODUCTION

Female harbor seals reach sexual maturity at three to four years of age (Bigg 1969a). Estrus and mating occur at the cessation of lactation, approximately five to six weeks after parturition (Fisher 1954, Bishop 1967, Bigg 1969a). After fertilization, there is a delay (approximately 2.5 months) in the implantation of the blastocyst. The gestation period is approximately nine months, and duration of pupping season is approximately 1.5 to 2 months (Bishop 1967, Bigg 1969a). Harbor seal individuals and populations have precise annual periods of pupping (Temte 1985). Pupping seasons, however, vary greatly among regions. Pupping begins as early as 1 February at Isla San Martin, Baja California, Mexico (30^{o} 30' N) and as late as 15 October in Puget Sound, Washington (Temte 1985).

In the northeastern Pacific Ocean, pupping seasons vary primarily with latitude (Bigg 1969b). This latitudinal cline was first described by Bigg (1969b) and later revised by Temte (1985). Bigg (1969b) described a two-directional cline occurring progressively earlier north and south of Washington State. In contrast, Temte (1985) described a cline of pupping occurring progressively later northward from Baja California, Mexico to the Pribilof Islands, Alaska. This discrepancy resulted from Bigg (1969b) including populations from Puget Sound and Strait of Georgia regions, which pup approximately three to five months later than coastal harbor seals at similar latitudes. Temte et al. (1991) separated *Phoca vitulina richardsi* into three subgroups: 1) northern British Columbia and Alaska (no latitudinal variation in birth timing); 2) Puget Sound (late birthing); and 3) Washington to Mexico (latitudinal variation in birth timing). Results of morphometric comparisons of harbor seals from these regions support the hypothesis of three discrete populations (Temte 1993). Latitudinal variation in birth timing also was reported for captive California sea lions (*Zalophus californianus*), but did not exist for captive northern sea lions (*Eumetopias jubatus*) and northern fur seals (*Callorhinus ursinus*; Temte 1993).

Newby (1973) described three distinct pupping periods in Washington State; 1) May, along the west coast, 2) July to August in North Puget Sound, and 3) mid-May to late September in South Puget Sound. Reasons for such variations within the same general latitude are unknown, although Bigg (1973) suggested that local populations may have adjusted to seasonal variations in food resources (especially shrimp, *Crangon* sp, for newly weaned pups). Lamont (1995) reported genetic substructuring between west coast and Puget Sound groups of harbor seals. Puget Sound and Strait of Georgia harbor seals may be more genetically similar to harbor seals off northern British Columbia and Alaska (which pup later in the year) than individuals along the west coast of Washington (Lamont 1995).

Pupping phenology data are required for determining optimal times to count harbor seal pups during annual aerial surveys. Maximum numbers of harbor seal pups occurred the fifth week of the pupping season in estuaries of western Washington (Jeffries and Johnson 1987, Stein 1989). Yearly counts of harbor seal pups provide information on population status and trends (Boveng et al. 1988, Gerrodette 1988, Goodman 1988).

Segregation of harbor seals ashore by age and sex has been reported during breeding seasons (Newby 1973, Pitcher 1977, Johnson and Jeffries 1983, Thompson 1989, Moss 1992, Kroll 1993) and nonbreeding seasons (Thompson 1989). Newby (1973) reported that during the first two weeks of parturition, female harbor seals formed distinct groups away from the main colony. Within these "nursery groups," female-pup pairs comprised a maximum of 32% of the harbor seals ashore at Tugidak Island, Alaska (Bishop 1967) and a maximum of 44% at Grays Harbor, Washington (Stein 1989).

Studies of harbor seals in Washington have been conducted primarily in coastal estuaries and Puget Sound. Minimal data have been collected for harbor seals off the San Juan Islands. The objectives of this study were to determine: 1) when the greatest number of harbor seal pups were present on haul-out sites; 2) if the greatest number of adult and subadult harbor seals ashore coincided with the greatest number of pups; and 3) if numbers of harbor seal pups and proportion of female/pup pairs were similar between two primary haul-out sites.

METHODS

Study Area

The study area was located in the northern San Juan Islands, Washington (48° 38' to 48° 49' N, 122° 45' to 123° 13' W; Fig. 1). This area is characterized by numerous islands, a tidal range of 3.6 m, strong currents (maximum of 7.7 km/hr), and a rocky shoreline. Harbor seal haul-out sites include reefs and rocky intertidal zones of islands. Haul-out sites in this region are numerous but typically used by fewer than 100 animals compared to coastal bays and estuaries, where haul-out groups are often greater than 200 harbor seals. Harbor seals at three haul-out sites (Clements Reef, Puffin Island, Skipjack Island; Fig. 1) were observed during this study. Selection of these haul-out sites was based on accessibility of observation points and the relatively large numbers of harbor seals ashore, especially mother/pup pairs (Washington Department of Wildlife unpubl. data).

Haul-out Site Observations

Between 2 July and 19 August 1991, 13 surveys of harbor seals ashore were conducted at Clements Reef, nine at Puffin Island, and eight at Skipjack Island. Between 24 June and 10 September 1992, 21 surveys were conducted at Clements Reef and 18 at Puffin Island. Harbor seals at Skipjack Island were not observed during 1992 to increase sampling effort at Clements Reef and Puffin Island. Harbor seals at each haul-out site were observed at least twice a week, with one observer per site. Harbor seals at Clements Reef were viewed from Ewing Island (Fig. 1), a distance of approximately 0.55 km. Harbor seals ashore on the northwest end of Puffin Island were viewed from the northeast corner of Matia Island, a distance of 0.38 km (Fig. 1). Observer heights above zero tide level were 10 m at Clements Reef and 13 m at Matia Island. The observation point on the northeast side of Skipjack Island was directly above (23 m) the haul-out site (Fig. 1).

Observations of harbor seals ashore began one to three hours before low tide and ended three to seven hours after low tide (when < 50% of the maximum number of harbor seals remained). Harbor seals were viewed with 22X and 15 - 60X spotting scopes. Scan surveys (Altmann 1974) were conducted each half-hour to count adult and subadult harbor seals and pups on the haul-out site. Environmental variables recorded were cloud cover, Beaufort sea state, and precipitation.

Analyses

Pupping season began when full-term harbor seal pups were first observed and was considered terminated when female/pup pairs were last observed on haul-out sites. Records of harbor seal pups brought to Wolf Hollow Wildlife Rehabilitation Center (WHWRC) provided additional data on parturition dates.

Data were not included in pupping phenology analyses if, due to disturbance, a uniform increase and decrease in harbor seal and pup counts was not observed during the survey day. Daily harbor seal pup counts were graphed to indicate the week when maximum harbor seal numbers occurred on haul-out sites. Differences between mean percentage of harbor seal pups at Clements Reef and Puffin Island were determined using a two-sample t test, after an arcsine transformation of data to meet assumptions (normal distribution and equal variances) of a parametric test (Zar 1984).

RESULTS

In 1991 and 1992, WHWRC records indicated parturition of premature harbor seal pups (with lanugo hair) occurred as early as 4 May and as late as 11 July. The first full-term harbor seal pups were received at WHWRC on 2 June 1991 and 11 June 1992 and the last pup on 19 October 1992. Full-term harbor seal pups were first sighted on haul-out sites within the study area the second week in June, but most pupping occurred in late June and early July. Harbor seal pups were last observed (or were distinguishable from yearlings) 24 August at Puffin Island and 5 September at Clements Reef in 1992.

Daily counts of harbor seal pups were highly variable, without a well defined peak in abundance throughout the season. In 1991, the greatest numbers of harbor seal pups at Puffin Island (18 to 26 pups) occurred during the last week in July and first week in August (Fig. 2a). Counts of harbor seal pups at Puffin Island in 1992 increased in early July (20 pups on 9 July), then remained fairly consistent until reaching a maximum of 28 pups on 9 August (Fig. 2a). The decrease in number of harbor seal pups ashore on 4 August 1991 was probably because sea conditions prevented pups from coming ashore and decrease on 6 August 1992 was because of rain. Counts of adult and subadult harbor seals at Puffin Island steadily increased from late June and early July, with maximums of

129 and 138 seals in 1991 and 111 and 115 seals in 1992 between 25 July and 9 August, then steadily decreased (Fig. 2b). An abnormally large number of harbor seals (178) were observed at Puffin Island on 9 September 1992, but no pups were present.

Numbers of harbor seal pups at Clements Reef increased from 10 July (two pups) to 11 August 1991 (14 pups) and 8 July (one pup) to 2 August 1992 (11 pups), then decreased. As at Puffin Island, a large number of harbor seal pups were counted on Clements Reef in early July 1992 (nine pups on 12 July; Fig. 2c). Counts of adult and subadult harbor seals at Clements Reef fluctuated (107 to 292 seals) throughout the pupping season, but exhibited no trend or peak in numbers (Fig. 2d).

Few harbor seal pups were sighted at Skipjack Island. A maximum of four harbor seal pups were counted on 20 July, numbers remained consistent until 2 August, then decreased to one pup on 17 August. Counts of adult and subadult harbor seals reached a maximum of 140 seals on 25 July then decreased to 39 on 17 August.

Numbers of harbor seals arriving at WHWRC in 1991 and 1992 were greatest during the first week in July (Fig. 3).

Mean number of harbor seal pups ashore at Puffin Island (mean = 15.11, SE = 1.63, n = 18) was significantly greater ($U = 305$, $p < 0.001$) than Clements Reef (mean = 3.83, SE = 0.71, n = 18) during the primary weeks of pupping (1 July to 14 August). Harbor seal pups also comprised a significantly ($t = 24.09$, $p < 0.05$) greater percentage of harbor seals ashore at Puffin Island (mean = 16.58%, SE = 1.07) than Clements Reef (mean = 2.63%, SE = 0.30). Harbor seal pups at Skipjack Island (mean = 3.0 pups, SE = 0.42) were a small percentage (mean = 2.9%, SE = 0.32) of the total number of harbor seals. Evidence of harbor seal birthing (two placentas) was observed only at Puffin Island. The cove on northwest Puffin Island was used primarily for pupping.

DISCUSSION

Calambokidis et al. (1985) reported 1 July as the onset of harbor seal pupping in the San Juan Islands, but did not report when the greatest number of pups occurred. Bigg (1969a) noted greatest numbers of harbor seal pups in southeastern Vancouver Island, B.C. in late July. In my study, parturition began the last week in June, with greatest number of harbor seal pups ashore the last week of July and first week of August. Greatest counts of harbor seal pups ashore were approximately five weeks after initiation of pupping as reported by Jeffries and Johnson (1987) and Stein (1989). Dates of greatest number of harbor seal pups in this study were similar to the 31 July to 8 August peak in numbers of harbor seal pups ashore at Protection Island, North Puget Sound (Calambokidis et al. 1985, Kroll 1993), but earlier than the 12 to 24 September peak at Gertrude Island, South Puget Sound (Calambokidis et al. 1985, Moss 1992).

Temte (1985) noted that timing of pupping for harbor seals in inland waters of Puget Sound, San Juan Islands, and Strait of Georgia were exceptions to the latitudinal clines reported by Bigg (1969b). Calambokidis et al. (1985) reported the apparent lack of movement of harbor seals between extreme southern and northern Puget Sound, based on pelage patterns and size, and suggested there were genetic differences. Using studies of captive harbor seals, Bigg (1973) suggested control of reproductive timing may be genetically based. Lamont (1995) indicated genetic differences between harbor seals in South Puget Sound (Gertrude Island) and coastal estuaries. Future genetic studies of harbor seals within Puget Sound, the San Juan Islands, and Strait of Georgia will provide necessary information to determine extent of reproductive isolation among regions.

Stein (1989) found the number of harbor seal births per hour in Grays Harbor, Washington was greatest the second and third week after onset of the pupping season. Bishop (1967) indicated that desertion of harbor seal pups was more common the first weeks of the pupping season and decreased as pupping progressed. Maximum birth rate and greatest desertion rate of harbor seal pups the first and second week of pupping probably explain the peak in arrival of harbor seal pups at WHWRC the first week in July.

Segregation of female-pup groups from remaining harbor seals during the pupping season has been observed in previous studies (Bishop 1967, Newby 1973, Johnson and Jeffries 1983, Slater and Markowitz 1983, Jeffries 1986, Thompson 1989, Kroll 1993). The cove on the northwestern side of Puffin Island was used primarily by harbor seal female-pup pairs during the pupping season. Although Clements Reef had consistently greater numbers of harbor seals, there were significantly fewer pups than at Puffin Island. Clements Reef was more exposed to sea conditions from the Strait of Georgia than the site on Puffin Island and was used primarily by male harbor seals (Chapter 3). Moss (1992) reported harbor seal female-pup pairs on the west coast of Washington used shallow water areas, protected from waves. Thompson (1989) also reported harbor seal female-pup pairs used sites which appeared more protected from sea conditions. Protected, shallow water areas may be important for the development of a harbor seal pup's motor skills (Allen et al. 1988).

In the San Juan Islands, aerial surveys to count harbor seal pups should be conducted the last week of July and first week in August. Females and pups ashore formed groups distinct from adult and subadult seals. Females with pups used the northwest cove of Puffin Island, a protected haul-out site. Areas such as Puffin Island require additional restrictions to prevent disturbance by humans (Chapter 2).

CHAPTER 2

DISTURBANCE

INTRODUCTION

In many locations, human disturbance is an important factor affecting the haul-out patterns of harbor seals. Harassment is any activity that causes a marine mammal to alter its normal behavior. Harassment caused by humans is prohibited by the Marine Mammal Protection Act (MMPA) of 1972. In contrast to pelagic marine mammals, changes in the behavior of pinnipeds on haul-out sites because of disturbance is relatively simple to measure. Long-term effects of disturbance, however, are often difficult to assess.

Disturbance may be as mild as causing an increase in heart rate with no visible change in behavior, as with telemetry-monitored bighorn sheep (*Ovis canadensis;* MacArthur et al. 1982) and white-tailed deer (*Odocoileus virginianus*; Moen et al. 1982) exposed to snowmobile traffic. In calving areas off Hawaii, humpback whale (*Megaptera novaenglia*) female-calf pairs avoid nearshore areas of intense human recreational activities (Glockner-Ferrari and Ferrari 1985, Salden 1988). Disturbance, however, can cause displacement and mortality. Disturbance-related mortality in pinnipeds can result from stampeding and pup abandonment (Johnson 1977) or by increased predation on young (Fay et al. 1986). Johnson (1977) estimated that in 1976, disturbance from low-flying aircraft may have caused mortality of greater than 200 (10%) harbor seal pups born on Tugidak Island, Alaska.

Sources of disturbance to harbor seals include boats, aircraft, seismic exploration, pedestrians, kayakers, and natural predators. Allen et al. (1984) reported that harbor seals on a haul-out site in Bolinas Lagoon, California were disturbed by humans on 71% of survey days, with non-motorized boats (primarily canoes) being responsible for most (33%) disturbances. Sources of disturbance to harbor seals ashore at Gertrude Island, Washington, included primarily unknown causes (77%) and secondarily human activities (11%) and coyotes (11%; Moss 1992). Humans, primarily boat operators, were the most common (57%) cause of harassment to harbor seals on Protection Island, Washington; unknown causes also were frequent (43%; Kroll 1993).

Contrary to expectations, responses of animals to pedestrians or non-motorized vehicles are sometimes greater than reactions to intense noises that can be detected at a greater distance (Richardson et al. 1991). When approaching white-tailed deer and mule deer (*Odocoileus hemionus*), hikers elicited startle and flight reactions at greater distances than operators of snowmobiles (Richens and Lavigne 1978, Eckstein et al. 1979, Freddy et al. 1986). Harbor seals ashore at Woodard Bay, Washington, allowed significantly ($p < 0.05$) closer approaches by powerboats than kayaks/canoes before entering the water (Calambokidis et al. 1991).

Occasional disturbance probably has little affect on harbor seal populations. Repeated disturbance, however, may have significant negative effects, especially at haul-out sites used for pup rearing (Richardson et al. 1991).

Allen et al. (1984) reported numbers of harbor seals returning to shore after a harassment in Bolinas Lagoon, California, were always less than before harassment. Harbor seal recovery rate (time for number of seals ashore to increase to preharassment levels) at Gertrude Island, Washington, was 80 min when disturbed by coyotes (100% of seals entered water), 43 min for human-related disturbances (70% of seals entered water), and 15 min for unknown disturbance source (56% of seals entered water; Moss 1992). Extent of recovery at Gertrude Island was dependent on the number of harbor seals harassed (Moss 1992).

While ashore, harbor seals may segregate by sex, age, and reproductive status (Allen et al. 1988). Terhune and Almon (1983) reported most Atlantic harbor seals in a haul-out group reacted similarly to harassments, but not all harbor seal groups reacted in a similar manner. Variability in reaction of harbor seal groups to disturbance may be attributed to variability in tolerance of disturbance among age, sex, or reproductive status.

Vigilance of harbor seals has been related to predator (Terhune 1985) and mate detection (Renouf and Lawson 1986). Terhune (1985) and da Silva and Terhune (1988) reported grouping by Atlantic harbor seals was beneficial for predator detection. These researchers, however, did not address the effect of harassment on vigilance of harbor seals.

Few studies have reported distances at which harbor seals ashore were disturbed by boats. Allen et al. (1984) reported human activities less than 100 m from harbor seals in Bolinas Lagoon, California, caused seals to leave the haul-out site more than human activities greater than 100 m from harbor seals ashore. People operating powerboats approached to a mean 40 m from harbor seals ashore at Woodard Bay, Washington, before the seals entered the water (Calambokidis et al. 1991). Results of these studies indicated distance that harbor seals tolerated approach by boats varied among regions.

Puget Sound and the San Juan Island region are unique waterways, ideal for commercial and recreational use (Everitt et al. 1980). Growth of the human population and increased development in this area have caused increased concern over potential environmental degradation (Everitt et al. 1980). Species of particular concern include the harbor porpoise (*Phocoena phocoena*), for which Flaherty and Stark (1982) have reported a negative correlation between number of sightings and boat traffic, killer whales (*Orcinus orca*), which are an important tourist attraction, and harbor seals, which use shoreline habitat.

In this study, data were collected to evaluate the extent of disturbance to harbor seals using haul-out sites in the northern San Juan Islands. The objectives of this study were to determine: 1) if human related activities were the primary source of disturbance; 2) if recovery (number of individuals returning to the haul-out site following a harassment) varied between flood and ebb tides; 3) if the extent of recovery was similar among Puffin Island, Clements Reef, and Skipjack Island; 4) if the extent of harassment was similar among size/age classes; 5) vigilance characteristics of harbor seals before and after a harassment; 6) if percentage vigilant was similar among haul-out sites; 7) if the distance between harbor seals and a boat causing a disturbance decreased with consecutive disturbances within a haul-out period; and 8) if the distance that disturbances occurred were significantly different between Puffin Island and Clements Reef.

METHODS

Counts of harbor seals were conducted at Clements Reef, Puffin Island, and Skipjack Island as described in Chapter 1. Two additional scan surveys (Altmann 1974) were conducted, at 10-min intervals, every 30 min. During one survey, harbor seal size structure (number of harbor seal pups, small - probably weaned pups and 1 yr-olds, and medium/large - subadults and adults) was recorded. Counts of harbor seal size structure included only those individuals that could be assigned a given category. During the final scan, a count was conducted of vigilant animals (head up, harbor seal alert but not oriented toward a disturbance source) and abundance of potential disturbance sources within 1.0 km of the haul-out site.

Data were collected for every potential source of disturbance that approached the haul-out site. Sources were divided into nine categories; airplanes, powerboats (including sailboats under motor power), sailboats, kayaks/canoes, people, Bald Eagles (*Haliaeetus leucocephalus*), unknown, or other. Vessel speed was classified as underway fast (creating a breaking bow wake), underway slow (nonbreaking bow wake), and drifting (motor not in gear or turned off). Vessel approach to a haul-out site was classified as direct (bow toward seals), angled (bow not toward seals and decreasing distance to haul-out site), and parallel (bow not toward seals and distance to haul-out site not decreasing). Harbor seal reactions to a disturbance were categorized as; 1) detection: ≥ 1 seal with head raised and oriented toward potential disturbance source; 2) alarmed: ≥ 1 seal moved from its resting place, but did not enter the water; and 3) harassed: ≥ 1 seal entered the water.

Positions of an approaching vessel were monitored using a Nikon NT2A or Pentax TH20D theodolite. Bearings to the approaching vessel and harbor seals exhibiting disturbance reactions were recorded, and the distance between them calculated using the formulas:

a) Distance from theodolite to boat (D_b) or seal (D_S)

$$D_b \text{ or } D_S = \frac{H}{\tan a},$$

where H is theodolite height and a is the angle between the horizon and boat or seal.

b) Distance from boat to seal (D_{bs}) using the angle between the boat and seal (b)

$$D_{bs} = \sqrt{D_b^{\,2} - D_s^{\,2} - 2 * D_b * D_s * \text{Cos} b}$$

Height of the theodolite above water was measured directly or estimated using a cosine prediction of tide height (San Juan Current and Tide Tables, published by Island Canoe, Bainbridge Island, Washington). The tidal constituent used was Port Townsend, Washington with a correction for Echo Bay, Sucia Island (approximately 1 km from Ewing Island and 6 km from Puffin Island). The observation point at Ewing Island (for Clements Reef surveys) was near a vertical rock ledge, which allowed the observer to directly measure theodolite heights (using a tape measure with float attached) above water level. Direct measurement of height above water was accurate to approximately 0.1 m. Direct measurement was not possible at Puffin Island, therefore, theodolite heights above water level were based on tide height predictions, which were accurate to approximately $\pm$ 0.3 m.

Analyses

Recovery was measured by the increase in number of harbor seals on the haul-out site after harassment. This measure of recovery requires the assumption that the majority of harbor seals returning to the haul-out site were the same as those harassed. Recovery was divided into four categories: 1) full recovery (number of harbor seals ashore after harassment increased to preharassment levels); 2) partial recovery (number of harbor seals ashore increased after the harassment, but did not reach preharassment levels); 3) no recovery (number of harbor seals ashore did not increase after harassment); and 4) no chance to recover (number of harbor seals ashore never increased after harassment due to repeated disturbances or rising tide washing over the haul-out site).

To test whether young harbor seals were less tolerant of disturbance than adults, the frequency of positive and negative changes in size composition (i.e. percentage of pups and small seals) before versus after a harassment were compared with a Chi-square Goodness of Fit test (Zar 1984). Data were combined for Puffin Island, Clements Reef, and Skipjack Island.

Terhune (1985) and da Silva and Terhune (1988) reported number of vigilant harbor seals was dependent on group size. To eliminate the potential effect of group size on vigilance, the original data were subsampled to produce subsets where the frequency distribution for number of harbor seals ashore was equal for each factor compared.

I initially tested whether the number of harbor seals vigilant was dependent upon the occurrence of a previous harassment during a haul-out period or the presence of a powerboat. Mean percentage of harbor seals vigilant before the initial harassment during a haul-out period was compared to after the initial harassment for Puffin Island, Clements Reef, and Skipjack Island using a Mann-Whitney (for data with non-normal distributions or unequal variances) or t test. Percentage of harbor seals vigilant with no potential disturbance source and a boat within 1 km of a haul-out site also were compared within sites (Mann-Whitney test). For example, vigilance data for seals at Puffin Island were divided into percentage of harbor seals vigilant before or after initial harassment. Data for before and after initial harassment were further subdivided into percentage vigilant with at least one boat within 1 km of the haul-out site or no disturbance source within 1 km of the haul-out site. Mean percentage of harbor seals vigilant with no potential disturbance source present were compared between Puffin Island and Clements Reef and Puffin Island and Skipjack Island (Mann-Whitney tests).

Distance of disturbance was defined as the distance between a boat and harbor seals ashore at the time of initial detection, alarm, or harassment (i.e. if a boat continued to approach, harassing additional harbor seals, the distance to the first group of harbor seals was used in analyses). I initially tested if the distance a disturbance occurred was dependent on a previous harassment of harbor seals during a haul-out period. Distances of disturbance for a single haul-out period, therefore, were separated into initial and subsequent harassments, and detections and alarms occurring before and after the initial harassment. There were insufficient data to subdivide by vessel approach angle, therefore, approach angle data were pooled. For analyses, data were separated into before/after and initial/subsequent harassment for vessel speed within each disturbance category (detection, alarm, and harassment). For example, data for distance of detection would be divided into distance that harbor seals detected a boat before or after an initial harassment. Data for before and after an initial harassment were further subdivided into distance of detection for powerboats approaching underway slow, underway fast, or drifting.

A Mann-Whitney two-sample test was used to determine significant ($\alpha = 0.10$) differences in mean distance of detection and alarm occurring before and after an initial harassment, and between initial and subsequent harassments during a haul-out period. A 0.10 critical value was selected because sample sizes were small and this was a test of independence of data to be used in further analyses. Frequency distributions of these data were non-normal and statistical power of the test could not be determined. Increasing the risk of a type one error by using a 0.10 critical value therefore was acceptable. When sufficient data were available, two-sample (Mann-Whitney and t) and Kruskal-Wallis tests were used to determine differences in distance of disturbance among vessels approaching underway slow, underway fast, and drifting. A two-factor Analysis of Variance (ANOVA) with square root transformation (Zar 1984) was used to test differences in mean distance of disturbance to harbor seals between Puffin Island and Clements Reef and among disturbance categories (detection, alarm, and harassment). Variances were tested with a F test for unequal sample sizes (Day and Quinn 1989). A Tukey multiple comparison test was used to interpret significant results of ANOVA analyses (Zar 1984, Day and Quinn 1989).

RESULTS

Harassments of harbor seals occurred during 71% of survey days at Clements Reef (n = 34), 77% at Puffin Island (n = 27), and 88% at Skipjack Island (n = 8). Powerboats caused 76% of harassments at Clements Reef (n = 91), 42% at Puffin Island (n = 64), and 46% at Skipjack Island (n = 24). Most harassments (74%, n = 96) involving powerboaters were those approaching the haul-out site to view harbor seals. Unknown disturbance sources were the second most common cause of harassment, 38% at Skipjack Island, 19% at Puffin Island, and 2% at Clements Reef. Bald Eagles accounted for 16% of harassments at Puffin Island, 2% at Clements Reef, and 0% at Skipjack Island. Harassment by kayakers was low (11%) for all sites. Because kayakers typically traveled near shore, they were a greater potential disturbance to harbor seals ashore than operators of powerboats. Fifty-five percent of kayakers (n = 11) within 1 km of haul-out site harassed harbor seals, whereas only 9% of powerboats (n = 436) within 1 km of a haul-out site caused harassment.

Sixty-nine harassments of harbor seals occurring at Puffin Island, Clements Reef, and Skipjack Island, were used for recovery analysis. The extent of recovery of harbor seals was related directly to whether the harassment occurred before or after low tide. Most harassments from which harbor seal numbers fully recovered (74%) occurred before low tide (n = 27 harassments), most partial recoveries (75%) and no recoveries (89%) occurred after low tide (n = 42 harassments, Fig. 4). There was no chance for harbor seals to recover after four harassments (Table 1) due to repeated harassments.

The extent of recovery following harassments of harbor seals was less at Puffin Island than Clements Reef and Skipjack Island. Numbers of harbor seals at Puffin Island often (41%) did not recover from harassments (Table 1). Numbers of harbor seals, however, often fully recovered from harassments at Clements Reef (52%) and Skipjack Island (45%; Table 1). Mean number of harbor seals harassed and proportions of harassments occurring before low tide (38 to 45%) were similar among haul-out sites.

Harbor seal recovery time varied from seven to 117 minutes (mean = 45.56, SE = 4.83, n = 27) for full recoveries and 10 to 228 minutes (mean = 59.05, SE = 10.23, n = 20) for partial recoveries. One third of harbor seals harassed (mean =33%, SE = 4.58) returned to a haul-out site during a partial recovery.

The percentage of harbor seal pups ashore did not decrease (n = 15) after harassment significantly more than it increased (n = 12, $X^2 = 0.183$, $p > 0.05$). The percentage of small harbor seals ashore decreased after 61% of harassments (n = 28), although the frequencies of decrease (n = 17) and increase (n = 11) were not significantly different ($X^2 = 0.1.286$, $p < 0.25$).

Trends in vigilance of harbor seals were consistent, although few were statistically significant. Nonsignificant results probably occurred because of small sample sizes using random subsampling of data. Numbers of harbor seals vigilant were comparable only when the effect of group size was eliminated (by randomly subsampling data). The percentage of harbor seals vigilant varied with each comparison, hence there was no single value for percentage of harbor seals vigilant at each haul-out site.

The percentage of harbor seals vigilant with no potential disturbance source within 1 km of the haul-out site was greater after than before an initial harassment at Clements Reef (U = 139.00, p = 0.098; Fig. 5a), Puffin Island (T = -0.686 with arcsine transformation, p = 0.496; Fig. 5b) and Skipjack Island (U = 51.00, p = 0.081; Fig. 5c). When a powerboat was within 1 km of the haul-out site, fewer harbor seals were vigilant after than before the initial harassment at Clements Reef (U = 162.00, p = 0.546; Fig. 5d), and Puffin Island (U = 198.50, p = 0.145; Fig. 5e). Although these differences were not statistically significant ($p > 0.05$), percentage vigilant was consistently different after than before an initial harassment and, therefore, data were not pooled.

Before an initial harassment at Clements Reef, slightly fewer harbor seals were vigilant when no disturbance source was present than when a powerboat was within 1 km of the haul-out site ($t = -0.424$ with arcsine transformation, $p = 0.674$; Fig.6a). At Puffin Island fewer harbor seals were vigilant when no potential disturbance source was present than when a powerboat was within 1 km of the haul-out site (Fig. 6b), although these differences were not statistically significant ($U = 41.50$, $p = 0.078$).

After an initial harassment, more harbor seals were vigilant when no potential disturbance source was present than when a powerboat was within 1 km of harbor seals, at Clements Reef (Fig. 6c) and Puffin Island (Fig. 6d). These differences were statistically significant at Clements Reef ($U = 213.00$, $p = 0.018$) but not at Puffin Island ($U = 198.5$, $p = 0.062$). There were insufficient data ($n = 2$) from Skipjack Island for these comparisons.

The percentage of harbor seals vigilant before initial harassment with no potential disturbance source present was significantly greater at Puffin Island (mean = 4.43%, SE = 0.44) versus Clements Reef (mean = 2.41%, SE = 0.47; $U = 229.5$, $p = 0.003$) and Puffin Island (mean = 6.40%, SE = 1.13) versus Skipjack Island (mean = 2.46, SE = 0.75; $U = 343.00$, $p = 0.002$).

Distances of disturbance of harbor seals were greater before than after an initial harassment for all detections and alarms, with only one exception. Harbor seals at Clements Reef detected powerboats approaching fast at a greater distance after than before harassment (Table 2). Distances of disturbance also were greater for all initial versus subsequent harassments of harbor seals (Table 2).

Harbor seals at Puffin Island detected powerboats approaching underway fast at a significantly greater ($U = 12.00$, $p = 0.046$) mean distance before than after an initial harassment. For powerboats underway slow, the initial mean distance of harassment was significantly greater ($U = 17.00$, $p = 0.086$) than subsequent mean distance of harassment (Fig. 7).

At Clements Reef, harbor seals detected powerboats underway slow at significantly greater mean distances ($U = 60.00$, $p = 0.085$) before than after a harassment, and the initial distance of harassment was significantly greater ($U = 15.00$, $p = 0.068$) than the subsequent distance of harassment (Fig. 7). These results indicated that distances of disturbance occurring after an initial harassment were dependent on previous disturbances. To eliminate potential bias in sampling animals that appeared to be more tolerant of the presence of powerboats, distances of disturbance occurring after an initial harassment of a haul-out period were not used in further analyses.

Distances of disturbance among powerboat approach speeds were tested to determine if data could be pooled. At Puffin Island, distances that harbor seals detected powerboats approaching underway fast and underway slow were not significantly different ($U = 18.00$, $p = 0.05$), therefore, these data were pooled (mean = 261 m, SE = 22.47, n = 20) for further analyses. There was no significant difference ($T = 0.076$, $p = 0.941$) in distance of detection for harbor seals at Clements Reef when powerboats approached underway fast versus underway slow. These data were pooled with distance of detection data for boats drifting toward Clements Reef (Table 2), resulting in a mean of 268 m (SE = 26.34, n = 14). There was no significant difference ($H = 0.214$, $p = 0.890$) in distance of harassments of harbor seals at Clements Reef when powerboats approached underway fast, underway slow, or drifting; therefore, these data were pooled (mean = 154 m, SE = 33.30, n = 7). If there were insufficient data to test distances of disturbance among boat speeds, data were used directly (harassment at Puffin Island and alarm at Clements Reef; Table 2), or pooled with those data in which boat speed was unknown (mean distance of alarm at Puffin Island was 196 m, SE = 25.00, n = 2).

There was no significant interaction of haul-out site and disturbance category (detection, alarm, and harassment; $F = 1.238$, $p = 0.300$). There also was no effect of haul-out site on mean distance of disturbance to harbor seals ($F = 1.006$, $p = 0.321$). There were significant differences in distances of disturbance among disturbance categories ($F = 9.751$, $p < 0.001$). Mean distances of detection, alarm, and harassment were not significantly ($p > 0.05$) different at Puffin Island. At Clements Reef, mean distance of alarm was significantly ($p = 0.028$) less than distance of detection, but not distance of harassment ($p = 0.078$). Distances of detection, alarm, and harassment were not significantly ($p > 0.05$) different between Puffin Island and Clements Reef.

DISCUSSION

Many islands in the San Juan Archipelago are state parks or have resort harbors that attract many boaters during the summer. Clements Reef was located near (0.6 km) Sucia Island, which was the most heavily visited state park in the northern islands. It was not surprising, therefore, that most disturbances at Clements Reef were caused by boaters. Relatively few kayakers ventured out to Clements Reef, Puffin Island, or Skipjack Island. Kayakers travel closer to shore and may cause harassment of harbor seals at a greater distance than powerboats (Calambokidis et al. 1991); therefore, as sea kayaking becomes more popular, there is a greater potential for disturbance to harbor seals ashore.

The differences in occurrence of unknown causes of harassments among haul-out sites is possibly a result of haul-out site topography. Harbor seals on Clements Reef had a

360° view of potential sources of disturbance compared with roughly 270° for Puffin Island and 180° for Skipjack Island. A harassment of unknown origin at Skipjack Island would often begin by several harbor seals looking toward the rocky cliff of the island, then entering the water. A prevalence of harassments of unknown origin have been documented at Gertrude Island (77%; Moss 1992), and Protection Island (43%; Kroll 1993). The relatively high occurrence of harassments by Bald Eagles at Puffin Island may have been due to a nearby Bald Eagle nest and the high percentage of harbor seal pups (a potential prey item of Bald Eagles). Skipjack Island also had an active Bald Eagle nest, but eagles were not observed harassing harbor seals.

Primary factors that affected recovery of harbor seals included duration of haul-out period, and number of harbor seals harassed. Harbor seals were less likely to return to the haul-out site later in the haul-out period. Differences in recovery of harbor seals before and after low tide were partly a result of recovery measured by the overall increase in animals, not the return of marked individuals to the haul-out site (i.e. number of harbor seals ashore typically began decreasing one to two hours after low tide). Moss (1992) noted a significant positive relationship between the number of harbor seals harassed and duration of recovery, but observed no significant difference in the percentage of harbor seals harassed or duration of recovery between ebb and flood tides.

Harbor seals may have moved to alternate haul-out sites after harassment, as only 39% of all harassments resulted in full recovery. Allen et al. (1984) reported the number of harbor seals that returned to a haul-out site after a disturbance in Bolinas Lagoon, California, was always less than the original number, and in most cases, harbor seals did not move to a nearby reef. Murphy and Hoover (1981) reported that harbor seals off the Kenai fjords, Alaska, often searched for a new haul-out site after harassment. Disturbance to harbor seals, therefore, may have considerable impact where haul-out space is limited (Murphy and Hoover 1981).

Young harbor seals may be less tolerant of disturbance than older harbor seals because they lack experience with disturbance sources. After repeated harassments, a core group of harbor seals often remained ashore. This was especially evident at Clements Reef and also was noted by Bishop (1967). Although certain groups of harbor seals (primarily small-sized) were occasionally observed entering the water before others during a harassment, there was no significant trend. Harbor seals of all ages were affected by disturbances.

Terhune (1985) compared aggregation behavior of harbor seals and vigilance with flocking behavior of avian species, which presumably allowed individuals to decrease their surveillance without decreasing the probability of detecting a predator (Caraco 1979, Studd et al. 1983). Terhune (1985) reported that harbor seals decreased scan duration and increased scan frequency as group size increased. Da Silva and Terhune (1988) identified group size as the only factor accounting for variation in scan time. Renouf and Lawson (1986) argued that only males increased scanning as mating season approached, and scans were related to important events in their mating system, not predators.

In the northern San Juan Islands, disturbance was an important factor affecting harbor seal vigilance. Vigilance also varied with presence of potential disturbance sources. Harbor seals remaining ashore after a harassment were more vigilant than before a harassment when no potential disturbance source was present and less vigilant when a powerboat was present. In contrast, harbor seals ashore before harassment were more vigilant when a powerboat was within 1 km of the haul-out site than with no potential source present. This trend was consistent among the three sites; the lack of statistical significance was probably a result of small sample sizes because of subsampling to control for group size. Vigilance of harbor seals remaining ashore after harassment differed from harbor seals harassed by the initial disturbance. Harbor seals that remained ashore after a harassment may have been more tolerant of powerboat approaches than those initially harassed and, therefore, scanned less frequently when a powerboat was audible.

When no disturbance source was present, the percentage of harbor seals vigilant before an initial harassment was significantly greater at Puffin Island than Clements Reef or Skipjack Island. Increased vigilance at Puffin Island may have been due to the greater numbers of harbor seal female/pup pairs than observed on Clements Reef or Skipjack Island (Chapter 1). Stein (1989) reported female harbor seals rested alert significantly more frequently when their pups were one to nine days old than when the pups were older. Newby (1973) reported a female harbor seal with a pup is "constantly alert and nervous."

Bishop (1967) observed that a nucleus of harbor seals, which usually included several very large animals, remained ashore unless danger became imminent. Terhune and Almon (1983) also noted that not all groups of harbor seals reacted to disturbances in the same manner. With one exception, the mean distance that harbor seals detected or were alarmed by an approaching powerboat was greater before an initial harassment of a haul-out period, and distances of initial harassments were greater than subsequent harassments. Although these results were based on small sample sizes, the consistent trend indicated that harbor seals were less easily disturbed (i.e. powerboats could approach closer to seals) following an initial harassment. Distance of disturbance may have been less after than before an initial harassment if harbor seals had become more tolerant of powerboat approaches, or if harbor seals that were less tolerant of disturbance did not return to the haul-out site after the initial harassment; recovery and vigilance data support the latter possibility. My results indicated that sampling one group of animals after an initial harassment during a haul-out period biases data by resampling animals that are more tolerant of disturbance.

The greater vigilance of harbor seals at Puffin Island, compared with Clements Reef and Skipjack Island, and the lack of recovery from a harassment, indicated that harbor seals at Puffin Island may be more easily disturbed. It would have been expected, therefore, that harbor seals at Puffin Island would enter the water when powerboats were farther away compared with harbor seals at Clements Reef. Mean distance of disturbance, however, was not consistently greater at Puffin Island. There were no significant differences in distances of detection, alarm, or harassment between Puffin Island and Clements Reef. Although harbor seals at Puffin Island were more vigilant for possible disturbances and fewer harbor seals recovered from a harassment than at Clements Reef, the distance at which they were disturbed was not significantly different.

Haul-out location also may have affected vigilance, distance at which harbor seals were disturbed, or recovery from harassment. Clements Reef is approximately 550 m from the nearest island; therefore, harbor seals can visually detect approaching powerboats at a greater distance than harbor seals at Puffin Island. Harbor seals using Puffin Island had a more restrictive view of approaching boats, possibly this is why harbor seals were more vigilant at Puffin Island. Differences in recovery may result from more alternate sites on Puffin Island that were not visible to observers compared to Clements Reef.

Allen et al. (1984) reported boats advancing toward, or remaining near, harbor seals ashore at Bolinas Lagoon, California, caused seals to leave the haul-out site more often than a boat simply moving past seals. Boats that traveled slowly, parallel to the haul-out site, and made no abrupt course or speed changes approached harbor seals at Clements Reef and Puffin Island with minimal disturbance. Greater sample sizes probably would have resulted in significant differences among distances of disturbance for various speeds and angles that powerboats approached harbor seals ashore.

Additional factors affecting the distance that harbor seals were disturbed included location of the haul-out site or time of the haul-out period. Harbor seals may more readily enter the water later in the haul-out period or during rain. Harbor seals also may become accustomed to close approaches (< 15 m) by boats in areas of high boat traffic (author's pers. obs.). These considerations were not addressed in this study.

Distances between harbor seals ashore and boats causing a disturbance were highly variable. During harassments, 50% of powerboats were 100 to 200 m from seals and 25% of powerboats were 200 to 300 m from seals, which indicated the minimum approach distance of 100 m, established by the National Marine Fisheries Service, was inadequate to prevent harassment of harbor seals in the northern San Juan Islands. Regulations for boats approaching haul-out sites should be conservative to account for this variability. Distances between harbor seals and boats causing harassment varies greatly among regions, so the same minimum approach distance can not be applied to all areas. Regulations also should restrict vessel activity (e.g. no abrupt changes in speed or course and traveling parallel to the haul-out site), especially near haul-out sites used for pupping, such as the northwest cove of Puffin Island. During pupping season, vessels should pass directly between Puffin and Matia Islands, remaining along the shoreline of Matia Island. Most harassments were caused by people approaching to view harbor seals, indicating the importance of distributing information and guidelines for wildlife viewing to the general public, possibly by including information with vessel registration.

Direct mortality of harbor seals, or complete abandonment of haul-out sites (greater than one haul-out period), because of harassment by humans was not observed during this study. Long-term impacts of harassment of harbor seal populations, however, are difficult to assess. Cases where marine mammals remain in heavily disturbed areas are easy to detect; therefore, cases of partial or complete abandonment of disturbed areas may be more common than evidence indicates (Richardson et al. 1991). Repeated harassments may cause harbor seals to relocate to more isolated locations further from foraging areas. Relatively few long-term studies of marine mammal populations have been conducted with reliable and consistent methods necessary to detect differences in habitat use (Richardson et al. 1991). Harassments increase energy expenditure of harbor seals by decreasing duration of haul-out period. Increased energy requirements have the greatest impact on harbor seal pups during nursing and adult/subadult harbor seals during molt when access to haul-out sites is important. Although harbor seals appear adaptable and continue to exist in many areas of direct human encroachment, consistent harassment could lead to reduced reproductive output. Hawaiian monk seals (*Monachus schauinslandi*) abandoned shore sites used by humans (Gerrodette and Gilmartin 1990). For Hawaiian monk seals, seemingly benign human activities caused small changes in the seals' behavior, resulting in demographic effects and a population decrease that lead to endangered status (Gerrodette and Gilmartin 1990). My study did not address long term impacts of harassment of harbor seals.

Differences in disturbance of harbor seals at Puffin Island compared with Clements Reef and Skipjack Island are likely due to the large percentage of harbor seal pups at Puffin Island. Because study sites were not replicated, however, these results are only suggestive. The differences in vigilance, recovery, and distance of disturbance source to harbor seals may be a result of the geographic characteristics of each site. Before conclusions can be drawn, differences between pupping and nonpupping sites require further study.

This study addressed the reaction of harbor seals to disturbance, not the effect of disturbance to individuals. With increasing recreational boating in coastal waters, the potential impact on harbor seals also increases. To assess the impact of disturbance on harbor seals, a more appropriate design would be to monitor activities before and after disturbance of radio-tagged harbor seals, especially mothers and pups, at several pupping and nonpupping sites. The investigator could then track harbor seals that left the haul-out site to determine if certain individuals are always the first to enter the water, and whether those individuals return to the haul-out site or consistently leave the area.

CHAPTER 3

MOVEMENTS AND DIVE PATTERNS

INTRODUCTION

Recent technological advances in tagging and tracking have greatly increased our knowledge of individual pinniped movements. Using time-depth recorders, satellite transmitters, and light sensors, researchers have recorded diving, foraging, and migration patterns of free-ranging pinnipeds (Gentry and Kooyman 1986, Le Boeuf et al. 1989, Bengtson and Stewart 1992, DeLong et al. 1992). Data indicating foraging areas, dive depth, and duration of dive are valuable in determining physiology and habitat requirements.

Investigators have used harbor seals with distinctly marked pelages, color tags, or flipper-mounted radio transmitters to document movements and haul-out behavior (Calambokidis et al. 1985, Brown and Mate 1983, Jeffries 1986, Stein 1989, Moss 1992). Because harbor seals are coastal animals, VHF telemetry can be used to follow animals at sea. Harvey (1987) conducted the first study of in-water activity patterns of Pacific harbor seals by employing head-mounted radio transmitters. Using this technique, researchers have studied diving and located foraging areas of harbor seals.

Harbor seals exhibit great seasonal site fidelity and typically localized (<25 km) movements (Pitcher and McAllister 1981, Harvey 1987, Yochem et al. 1987, Thompson and Miller 1990, Torok 1994). At San Miguel Island, California, Stewart and Yochem (1983) resighted 73% (11 of 15) of tagged harbor seals exclusively at their respective capture sites. Similarly, Harvey (1987) reported 92% of tagged harbor seals along the Oregon coast were located within 8 km of their release sites.

Harbor seals often use consistent foraging areas (Thompson and Miller 1990, Torok 1994). Durations of most feeding trips for three adult harbor seals in the Moray Firth, Scotland, were less than 12 hrs (maximum duration was six days) and data from one individual indicated harbor seals swam directly to and from foraging locations (Thompson and Miller 1990). Radio-tagged harbor seals (n = 21) in San Francisco Bay, California, never visited more than two foraging areas within a 24-hr period (Torok 1994).

Thompson (1989) reported seasonal variation in distribution of harbor seals near Orkney, Scotland. Long distance movements of harbor seals (>100 km) off Oregon and Washington were reported by Harvey (1987) and Jeffries (1986), but were not common. Shifts in population distributions presumably occur as harbor seals exploit seasonally abundant food resources and occupy sites for pupping, breeding, and molting (Brueggeman 1990).

Harbor seals are small, coastal pinnipeds and relatively shallow divers compared with large, pelagic species such as elephant seals (*Mirounga angustirostris*), which occasionally exceed 1,000 m depth and 1 hr duration during diving (Le Boeuf et al. 1989, DeLong and Stewart 1991). Mean duration of dive for harbor seals range from 0.50 min to 3.33 min and mean duration at surface from 0.33 min to 1.04 min (Harvey 1987, Torok 1994). Harvey (1987) reported a maximum duration of 11.35 min for dives of seven radio-tagged harbor seals along the coast of Oregon.

Frequency distributions of duration of dive for pinnipeds are often multimodal (Harvey 1987, DeLong and Stewart 1991, Boyd and Croxall 1992). Variation in duration of dive for crabeater seals in the Weddell Sea, Antarctica, corresponded to dive depths and activities of presumably foraging, traveling, and exploratory dives (Bengtson and Stewart 1992). Duration of dives also may vary with diurnal and nocturnal activities (Delong and Stewart 1991, Bengtson and Stewart 1992, Boyd and Croxall 1992).

Studies of harbor seal movement patterns in Washington have been conducted in the Columbia River (Jeffries 1986), bays along the west coast (Johnson and Jeffries 1983, Stein 1989), and in South Puget Sound (Washington Department of Wildlife unpubl. data). This was the first study in which harbor seals were radio-tagged to assess movements and dive patterns off the San Juan Islands; an unique oceanographic region compared with bays and outer coastal waters.

The objectives of this study were to: 1) determine haul-out site fidelity of tagged harbor seals; 2) locate foraging areas; 3) determine duration of dive and duration at surface for activities of milling, traveling, and resting; and 4) compare activities and durations of nocturnal and diurnal dives.

METHODS

Harbor seals were captured on rocky haul-out sites using methods developed by Jeffries et al. (1993). By rapidly setting a net in front of the haul-out site, this method took advantage of the harbor seal's tendency to remain near shore after entering the water. The capture net was deployed at high speed from a lead boat while a second boat sped to shore to secure the end of the net. The net was pulled to shore similar to a beach seine. Captured harbor seals were removed and placed in individual hoop nets to await tagging and release. The harbor seals were physically restrained without sedatives. Although this capture method was designed for use on smooth substrates, it was successful on parts of Clements Reef and a reef near Puffin Island, which had relatively even contours. Thirteen harbor seals were captured, weighed to the nearest kg, measured to the nearest cm, tagged with three plastic hind flipper tags (two numbered and one with a VHF radio transmitter, Advanced Telemetry Systems, ATS, 164-165 MHz). Orange, numbered patches were glued to the dorsal pelage. Eleven harbor seals were captured at Clements Reef and two at Puffin Island Reef (Fig. 1). All harbor seals captured and tagged were males (six adults and seven subadults; Table 3). Transmitters were glued (5-min epoxy) to the pelage on top of the head (Harvey 1987, Jeffries et al. 1993) of five (two adults and three subadults) of the thirteen animals. Transmission range was approximately 8 km with a receiver at the shore site (antenna height approximately 9.1 m atop a lighthouse on the west end of Patos Island; Fig. 1) and 4 km aboard a boat with an antenna 1.5 m above the waterline.

Telemetry surveys (n = 13) were conducted biweekly (21 June and 11 September 1992) at nine haul-out sites (Fig. 1) to locate radio-tagged harbor seals. Surveys were conducted from a 5.2-m Boston Whaler or a 7.3-m Aluminum Marine Patrol 24. Haul-out sites were surveyed in a systematic order but a random direction. Frequencies also were monitored during concurrent telemetry surveys for a separate study in the southeastern Gulf Islands and Boundary Bay, B.C., and Drayton Harbor, Washington (Fig. 1). Surveys began 2-hrs before low tide and were terminated 2-hrs after low tide. Telemetry surveys were conducted using an ATS receiver and a two- or three-element yagi antenna.

Movements and dive patterns of five harbor seals with head-mounted transmitters were monitored to determine range and foraging locations within the study area. Five harbor seals were tracked in a random order every one to two weeks between 22 June and 9 September 1992. A 10-hr sampling period allowed 5-hrs for each of two harbor seals to be located and tracked. I attempted to obtain equal sample sizes of diurnal and nocturnal harbor seal activities. Tracking began and ended by attempting to locate each harbor seal from atop the lighthouse at the west end of Patos Island (Fig. 1). If a tagged harbor seal was not located within the study area or was ashore during its allotted day and time, the next randomly selected harbor seal was tracked. Harbor seals were tracked from a 5.2-m

Boston Whaler. Durations of dives were recorded to the nearest 1 sec using a digital watch. All five frequencies were scanned at the beginning and end of each survey to obtain locations for harbor seals. This sampling scheme was designed to provide more independent samples of individual activities, dive patterns, and locations, compared with 24-hr monitoring of one individual.

In-water activity states of harbor seals were divided into four categories; milling (remaining in a localized area and not moving in a specific direction), traveling (moving consistently in a single direction), resting (remaining in one location, with fairly consistent durations of dive and duration at surface), and nearshore (erratic pattern of diving and surfacing, seal usually near haul-out site). Milling was presumably, but not restricted to, foraging. Some foraging likely occurred during traveling and nearshore movements.

Locations of waterborne harbor seals (with head-mounted transmitters) were determined by locating the boat's position (using compass bearings to landmarks and triangulating), then determining direction and estimated distance to a visible harbor seal or to a strong and consistent transmitter signal from the tagged seal. The boat also was repositioned to determine the signal direction and location. To calibrate signal strength and direction estimates for a given day, a reference transmitter was located on the Clements Reef buoy. Employing these techniques, locations of harbor seals were accurate to within approximately 0.25 km^2. Seafloor depth for each harbor seal location was estimated using a National Oceanic and Atmospheric Administration navigational chart (#18421).

Analyses

Haul-out site fidelity was defined as the percentage frequency a harbor seal was located at a particular haul-out site,

$$\frac{S}{A} * 100,$$

where S is the frequency haul-out site S was used and A is the frequency the seal was located ashore.

An inherent problem with recording consecutive durations of dive is the data are not independent for statistical comparisons among harbor seals (i.e. long dives tend to follow long dives). To avoid the problem of dependence, a random subsample of durations of dive may be statistically compared (DeLong and Stewart 1991, Bengtson and Stewart 1992, Harvey, Moss Landing Marine Laboratories, Moss Landing, California pers. comm.). This was not possible, however, with the small sample sizes ($n < 225$) obtained in this study. Mean duration of dive and duration at surface, therefore, were statistically compared among activity states within data of individual harbor seal and not among seals. Mean duration of dives was determined for each harbor seal. Dives with associated activity state (not all dives could be associated with a particular activity state) were sub-divided by activity state. Diurnal and nocturnal patterns of dives also were examined. Diurnal dives were defined as those occurring between sunrise and sunset and nocturnal between evening civil twilight and morning civil twilight. Mean durations of dives and durations at surface among activity states were compared within data of individual harbor seal using a one-factor ANOVA or a Kruskal-Wallis test. A Tukey multiple comparison test was used when an ANOVA analysis indicated significant results. A nonparametric Tukey-type post hoc test (Zar 1984) was used for significant Kruskal-Wallis results. Pearson product-moment (harbor seal #165) and Spearman's rank (harbor seals #264, #674, #915) correlation analyses were used to determine relationships between duration of dive and duration at surface.

RESULTS

Movements

Within the study area, harbor seal haul-out site fidelity was great, ranging from 100% for harbor seals #044, #155, #644, #674, #915, and #954 to 33% for #810 (Table 4). Percentage of time a harbor seal was ashore during surveys (n = 13) ranged from 8% for #014 to 54% for #385 and #674 (mean = 40%, SE = 4). Only five harbor seals (#155, #264, #505, #915) tagged in the San Juan Islands were located during 13 surveys (21 June to 11 September 1994) in the Gulf Islands and Boundary Bay, B.C. or Drayton Harbor, Washington. The greatest recorded movements were for harbor seals #954 (28 km to Boundary Bay, B.C.; Fig. 1) and # 264 (26 km to Georgeson Island, B.C.; Fig. 1). Harbor seal #155 was located at Boiling Reef, B.C. (11 km from the capture site; Fig. 1) and harbor seal #505 was located at Cabbage Island, B.C. (15 km from the capture site; Fig. 1).

Harbor seal #155 was located within the waters of the study area (Fig. 8) during two of seven (29%) tracking efforts before losing the head-mount transmitter the first week in August (Table 5). This harbor seal was found ashore during 29% of the haul-out site surveys (n = 7) before 8 August, indicating it occurred primarily outside the study area during this time. Harbor seal #155 was located via flipper-mounted transmitter, however, at Clements Reef during 67% of the surveys (n = 6) in August and September (Table 4).

Harbor seal #165 was found ashore at Skipjack or Bare Islands during 62% of the surveys of haul-out sites (n = 13, Table 4), and located in the water during 85% of the tracking surveys (n = 14, Table 5). Eighty percent of 15 in-water locations for harbor seal #165 were less than 2 km from Skipjack and Bare Islands (Fig. 8).

Harbor seal #264 was located in the water during 73% of the tracking surveys (n = 15, Table 5), but was only recorded ashore during 35% of the surveys of haul-out sites (n = 13, Table 4). Seventeen in-water locations of harbor seal #264 were less than 5 km from Clements Reef and Ewing Island Reef (Fig. 8), the only haul-out sites in the study area used by this harbor seal.

Harbor seal #674 was frequently located (87%) during tracking surveys (n = 15, Table 5). Twenty-six in-water locations of harbor seal #674 were primarily between Sucia and Patos Islands (Fig. 8). Harbor seal #674 always was located within 3.7 km of Clements Reef, the only haul-out site within the study area used by this harbor seal (Table 4).

Harbor seal #915 was located ashore during 63% of the haul-out site surveys until 11 August (n = 8), then was never relocated (Table 4). This harbor seal was located in the water during 75% of tracking surveys (n = 8) before losing the head-mount transmitter the second week in August (Table 5). Seven in-water locations of #915 were within 5.6 km of north Sucia Island (Fig. 8).

Dive Patterns

Tracking effort included: 0.5 hrs during one survey for harbor seal #155, 16 hrs during five surveys for harbor seal #165, 13 hrs during six surveys for harbor seal #264, 10.75 hrs during five surveys for harbor seal #674, and 8.25 hrs during two surveys for harbor seal #915 (Table 5). Harbor seal #155 was eliminated from dive analyses due to small sample size.

Frequency distributions of duration of dive for harbor seals were normal (Fig. 9a), bimodal (Figs. 10a and 11a), and trimodal (Fig. 12a). Harbor seal dives for which an activity state could be assigned were subdivided into milling, traveling, nearshore, and resting behaviors. With few exceptions, dividing multimodal frequency distributions of duration of dive by activity states resulted in subsets with unimodal distributions (Figs. 9b, 10b, and 12b). This stratification reduced variability of the data; standard deviations for subsets were typically less than overall.

Mean durations of dives among activity states were significantly different for harbor seals #165 (ANOVA with log transformation, $F = 8.910$, $p \leq 0.001$), #264 (Kruskal-Wallis $H = 56.221$, $p < 0.001$), #674 (Kruskal-Wallis $H = 63.273$, $p < 0.001$), and #915 (Mann-Whitney $U = 561.0$, $p = 0.001$). Mean duration of dives were consistently greater for milling (4.00 - 6.22 min) than traveling (3.16 - 3.57 min) and nearshore (1.52 - 3.59 min; Table 6). The only harbor seal observed resting in the water was #165. Harbor seal #915 was not observed traveling.

Mean duration at surface also was greater for milling than traveling, nearshore, and resting (Table 6). These differences were significant for harbor seals #165 (ANOVA with log transformation, $F = 10.887$, $p \leq 0.001$), #264 (Kruskal Wallis $H = 47.163$, $p \leq 0.001$), and #674 (ANOVA with log transformation, $F = 7.942$, $p < 0.001$; Table 6). Mean duration at surface while milling was similar to nearshore movements for harbor seal #915 (Mann-Whitney $U = 407.5$, $p = 0.451$; Table 6). The maximum recorded dive was 15.42 min (harbor seal #264).

There were two cases when foraging was confirmed during harbor seal milling behavior. Other indications of foraging while milling included the presence of other harbor seals, harbor porpoise, baitfish at the surface, and occasionally diving birds such as Rhinoceros Auklets (*Cerorhinca monocerata*) and Common Murres (*Uria aalge*).

Correlation analyses indicated significant ($p < 0.001$) positive relationships between duration of dive and duration at surface for all harbor seals, although the data were variable ($r < 0.588$; Fig. 13).

Trends in duration of nocturnal versus diurnal dives of harbor seals were inconsistent. Duration of diurnal dives for harbor seals #264 and #915 were greater than nocturnal (Table 7). Duration of diurnal dives for harbor seal #674 were less than nocturnal, but were similar for harbor seal #165 (Table 7). Although sample sizes of duration of nocturnal and diurnal dives were similar (except for harbor seal #165), not all dive behaviors were observed equally day and night (Table 7). These differences probably accounted for the variability in results. For example, harbor seal #264 was observed milling during two diurnal and no nocturnal surveys, resulting in greater mean duration of diurnal dives.

Harbor seals were located in water depths of 10 to 180 m (mean = 79 m, SE = 9, n = 38). Mean water depth was 110 m (SE = 15, n = 11) for milling activities, 70 m (SE = 25, n = 7) for traveling and 40 m (SE = 15, n = 4) for nearshore movements. Maximum water depth in the study area was 256 m.

DISCUSSION

Movements

Haul-out site fidelity is typically great during pupping and molting seasons with most harbor seals using no more than two sites (Pitcher and McAllister 1981, Stewart and Yochem 1983, Yochem et al. 1987, Thompson 1989). Torok (1994) reported similar results during the pupping season in San Francisco Bay, California (mean = 1.7 sites) but noted a significant increase in the number of sites used during the nonpupping season (mean = 4.1 sites). Only harbor seal #810 used more than two haul-out sites during my study. Six harbor seals (46%) exclusively used the haul-out sites where they were captured. Stewart and Yochem (1983) found similar results at San Nicolas Island, California (50%, n = 8). Yochem et al. (1987), however, reported 81% (n = 16) of tagged harbor seals used one haul-out site at San Miguel Island, California, and Pitcher and McAllister (1981) reported 74% (n = 42) of harbor seals used one site at Tugidak Island, Alaska. Stein (1989) reported 68% (n = 21) of female harbor seals sighted more than five times within Grays Harbor, Washington, in 1985 were resighted in 1986. This indicated the fidelity of harbor seals to selected sites. Harbor seals may consistently use haul-out sites other than capture locations, as observed in this study (harbor seals #165 and #644) and noted by Pitcher and McAllister (1981) and Yochem et al. (1987). This was possibly a result of disturbance from capture and tagging, or the capture location was not the harbor seal's primary haul-out site. Numerous haul-out sites surrounding the study area also may have been used by tagged harbor seals. Four harbor seals were relocated up to 28 km north and northeast of the study area where concurrent surveys were conducted. Harbor seal #505 vacated the study area for 10 days early in the pupping season. Three harbor seals moved out of the study area in mid-August and early September and were not relocated within the study area, although surveys were only conducted until 11 September.

Subadult harbor seals often are highly mobile (Mansfield 1967, Jeffries 1986, Thompson 1989). Tagged adult and subadult harbor seals off the San Juan Islands were similar in their movements and use of haul-out sites during the pupping season. Surrounding areas, however, were not regularly surveyed so movements of age classes outside the relatively small study area were unknown.

Three of the five harbor seals with head-mount transmitters (#165, #264, and #674) were frequently located and used consistent foraging areas. Harbor seals #155 and #915 were difficult to locate and their transmitters detached in early August. Use of consistent foraging areas has been noted in previous studies of harbor seals (Thompson and Miller 1990, Torok 1994) and fur seals (Loughlin et al. 1987). The area between

Sucia and Patos Islands apparently was an important foraging site for all harbor seals in this study. Untagged harbor seals also were often observed in these areas. Strong tide rips form at these locations due to subtidal reefs and currents from water moving in and out of the southern Strait of Georgia. Harbor seal #165 was consistently located in an area near Skipjack and Bare Islands, which has similar oceanographic features. Primary foraging areas used by harbor seals in this study were within 4 km of their respective haul-out sites. Harbor seals often moved to and from tide rips during tracking efforts indicating potential use of rips for capturing prey. Tide rips often form around reefs or shoaling seafloor (Barenblatt et al. 1985), so shallow water (< 200 m) also may have been an important feature for the harbor seals. On 22 September 1992, a group of harbor seals were observed feeding in association with harbor porpoise, a minke whale (*Balaenoptera acutorostrata*), and gulls (*Larus* sp.) on a large school of Pacific herring (*Clupea pallasii*). On 22 July 1992, harbor seals (including #165) also were observed feeding on salmon (*Oncorhynchus* sp.) in a tide rip. Salmon tend to move in main currents and orient along axes of tidal currents (Stasko et al. 1976). Other researchers have reported associations of harbor porpoise (Everitt et al. 1980, Flaherty and Stark 1982, Raum-Suryan 1995) and Dall's porpoise (*Phocoenoides dalli*; Miller 1989) with tide rips in Puget Sound and the San Juan Islands. From scat samples collected on Smith Island (45 km south of my study area), Calambokidis et al. (1978) reported zoarcid fishes (61% occurrence) and Pacific herring (11%) dominated harbor seals diets in July and August. Shallow areas where tide rips form may provide harbor seals with accessible bottom fishes and concentrate schooling fishes. To resolve these questions it would be necessary to study harbor seal food habits in the northern San Juan Islands and sample tide rips for prey fishes.

Dive Patterns

Duration of dive often varies within and among individual harbor seals (Harvey 1987) and elephant seals (DeLong and Stewart 1991). Variability in duration and depth of dives of individual seals has been attributed to geographic location (prey depth and behavior, bottom depth; DeLong and Stewart 1991) and body mass (Kooyman et al. 1983, DeLong and Stewart 1991). Differences in duration of dives among harbor seals in this study were likely a result of areas frequented. Harbor seals #264 and #915 had the greatest overall mean duration of dive and were most frequently located in deeper waters north of Sucia Island (southern Strait of Georgia). Harbor seals #264 and #915 also were the only adults for which dive data were collected.

Multimodal frequency distributions of duration of dives have been reported for harbor seals (Harvey 1987, Boness et al. in press), Antarctic fur seals (*Arctocephalus gazella*; Boyd and Croxall 1992), Gentoo Penguins (*Pygoscelis papua*; Williams et al. 1992), and King Penguins (*Aptenodytes patagonicus*; Kooyman et al. 1992). Researchers using time-depth recorders reported that modal distributions of duration of dive corresponded with the distribution of dive depths (DeLong and Stewart 1991, Boyd and Croxall 1992, Kooyman et al. 1992, Lydersen and Hammil 1993). Multimodal distributions result in a great variability about the mean. Subdividing dive data by depth or activity categories is a way of reducing variability and providing a more detailed description of an animal's dive patterns.

When divided into activity states, dive patterns exhibited similar trends among harbor seals. Mean duration of dive while milling was significantly greater than traveling and nearshore diving activities of all harbor seals, except #165. This implies that harbor seals dive longer when actively foraging. This could have been a result of duration of time searching for food, or the depth at which harbor seals were foraging. Harbor seals were typically in deeper water when observed milling compared with other activities. Differences in mean duration of dive among activity states, therefore, may be a result of dive depths.

It is important to emphasize the limitations of these results. Harbor seals were tracked during a two-month period, so conclusions are limited to activities during the pupping season. Although multiple samples of relatively short (< 5.5 hr), independent tracking periods were collected, sample sizes of dive data were greatly reduced when subdivided by activity patterns. For example, harbor seal #165 was monitored during six tracking surveys (215 dives), but milling was only observed during two surveys (47 dives) and nearshore movements (58 dives) during one survey.

Mean duration at surface and duration of dive indicated similar results among activity states. Mean duration at surface was greater when harbor seals were milling, indicating longer, more strenuous, or potentially deeper dives resulted in greater duration at surface. Correlation analyses indicated significant positive relationships between duration of dive and duration at surface, although the correlation explained only 10% to 34% of the variability. These results indicated that generally greater mean duration of dives associated with milling activities corresponded with greater mean duration at surface. Long durations at surface, however, did not necessarily follow long dives, nor short durations at surface for short dives. Results of this study indicated a stronger correlation between duration of dive and duration at surface than that reported for crabeater seals (*Lobodon carcinophagus*; Bengtson and Stewart 1992) and northern elephant seals (Delong and Stewart 1991). Duration of dives and duration at surface of crabeater seals differed significantly between shallow (< 50 m) and deep (> 50 m) dives, but overall they were not related ($r^2 = 0.001$). Delong and Stewart (1991) also found that duration of dive for northern elephant seals explained ≤ 2% of the variability in duration at surface. Duration at surface may be a function of diving activity (i.e. energy expenditure while foraging, traveling, or resting) rather than duration of dive.

Comparisons of nocturnal and diurnal patterns of dive are often interpreted as a change in foraging strategies in response to prey availability (Delong and Stewart 1991, Bengtson and Stewart 1992, Boyd and Croxall 1992). DeLong and Stewart (1991) reported that diurnal dives of male northern elephant seals were approximately 200 m deeper than nocturnal dives, presumably a response to vertically migrating prey species. Nocturnal foraging of harbor seals may be a result of prey availability or permit a diurnal haul-out pattern. Crabeater seals in the Weddell Sea have distinct diurnal haul-out and nocturnal diving patterns, presumably in response to the crabeater seal's principal prey, Antarctic krill (*Euphausia superba*; Bengtson and Stewart 1992). Off the San Juan Islands, milling activities of harbor seals were observed during nocturnal and diurnal tracking surveys. Actual foraging was only observed during daylight; however, similar diving activities also were monitored at night. Duration of dive data collected during this study indicated no consistent diurnal or nocturnal pattern. These results indicated that harbor seals off the northern San Juan Islands were not strictly nocturnal or diurnal foragers. Tide rips apparently were used by harbor seals when foraging, and occurrence of tide rips throughout a 24 hour period would allow harbor seals to forage independent of time of day. Sample sizes in this study were insufficient to compare the extent of diurnal and nocturnal activity patterns. Larger sample sizes and longer tracking periods including recording the duration of diurnal and nocturnal haul-out bouts would be necessary to answer this question.

CONCLUSIONS

Arrival of the first full term harbor seal pups in the San Juan Islands occurred the first week in June with most pupping beginning in late June and early July. Maximum numbers of harbor seal pups on haul-out sites occurred the last week in July and first week of August. Maximum number of adult and subadult harbor seals at Puffin Island also occurred at this time, whereas counts of adult and subadult harbor seals at Skipjack Island and Clements Reef indicated no trend. Segregation of mothers and pups from other harbor seals occurred; a greater percentage (and total number) of harbor seal pups were observed at Puffin Island compared with Clements Reef and Skipjack Island.

Disturbance of harbor seals on haul-out sites was commonly caused by humans, although unknown causes also were frequent at Skipjack Island. Harbor seals on Puffin Island were more vigilant and less often returned to the haul-out site after harassments, suggesting less tolerance of disturbance compared with harbor seals on Clements Reef and Skipjack Island. Disturbance of harbor seals caused an increase in vigilance. Few harassments resulted in full recovery of harbor seals, and harbor seals remaining ashore after an initial harassment of a haul-out period allowed closer approach by powerboats, indicating that individuals less tolerant of disturbance did not return to haul-out sites. Results of this study indicate the variability in response to disturbance among individuals and the potential bias in sampling animals that remain after a disturbance, or in areas where disturbances are frequent. Distance at which powerboats caused a harassment were variable, ranging from 28 m to 260 m. Boating regulations near harbor seal haul-out sites should primarily restrict activity of vessel (speed and approach angle) and secondarily, distance from harbor seals (based on distance that harbor seals detected boats). Boating regulations are particularly important near harbor seal pupping areas such as Puffin Island.

Harbor seals exhibited haul-out site fidelity and used consistent foraging areas within the study area. Uneven, shallowing seafloor and tide rips appeared to be important characteristics of feeding areas. Milling, and presumed foraging, was observed day and night, but this study did not address whether feeding occurred disproportionately throughout a 24-hr period. It appeared that harbor seal dive patterns varied in relation to activity and seafloor depth. Duration of dives varied significantly among activity states, which corresponded with varying seafloor depths. Duration at surface also varied significantly among activity states. Weak positive relationships existed between overall duration of dives and duration at surface. No trend was evident in nocturnal and diurnal durations of dives.

With increasing numbers of harbor seals in northern Washington waters, it is essential to determine habitat requirements influencing harbor seal distribution and their potential conflicts with fishery operations. Because harbor seals appear to forage nocturnally and diurnally, often in association with tide rips, tracking diel activities, analyzing prey from fecal samples, and sampling prey in foraging areas (particularly within tide rips) will increase our understanding of the ecology of harbor seals off the northern San Juan Islands.

LITERATURE CITED

Allen, S. G., D. G. Ainley, and G. W. Page. 1984. The effect of disturbance on harbor seal haul out patterns at Bolinas Lagoon, California. Fish. Bull. 82(3):493-500.

Allen, S. G., C. A. Ribic, and J. E. Kjelmyr. 1988. Herd segregation in harbor seals at Point Reyes, California. Calif. Fish and Game 74(1):55-59.

Altmann, J. 1974. Observational study of behavior: sampling methods. Behavior 49:227-267.

Barenblatt, G. I., I. A. Leykin, A. S. Kaz'min, V. A. Kozlov, V. A. Razzhivin, I. A. Filippov, I. D. Frolov, and S. I. Chuvil'chikov. 1985. Rips in the White Sea. Suloy v Belom more. Doklady Akademii nauk SSSR. vol 281, no. 6, pp. 1435-1439.

Beach, R. J., A. C. Geiger, S. J. Jeffries, S. D. Treacy, and B. L. Troutman. 1985. Marine mammals and their interactions with fisheries of the Columbia River and adjacent waters, 1980-1982. Third Annual. Rep. NOAA, NMFS Grant No. 80-ADB-0012. 316 pp.

Bengtson, J. L. and B. S. Stewart. 1992. Diving and haulout behavior of crabeater seals in the Weddell Sea, Antarctica, during March 1986. Polar Biol. 12:635-644.

Bigg, M. A. 1969a. The harbor seal in British Columbia. Fish. Res. Bd. Canada Bull. no. 172. 33 pp.

_________ 1969b. Clines in the pupping of harbour seal, *Phoca vitulina*. J. Fish. Res. Board Can. 26:449-455.

_________ 1973. Adaptions in the breeding of the harbour seal, *Phoca vitulina*. J. Reprod. Fert., Suppl. 19:131-142.

_________ 1981. Harbour Seal, *Phoca vitulina* Linnaeus, 1758 and *Phoca largha* Pallas, 1811, p. 1-27 In S. H. Ridgway, and R. J. Harrison [ed.] Handbook of marine mammals. Vol.2 Seals. Academic Press, London, U.K. 359 pp.

Bishop, R. H. 1967. Reproduction, age determination, and behavior of the harbor seal, *Phoca vitulina l.* in the Gulf of Alaska. M.S. Thesis. Univ. of Alaska, Fairbanks. 121 pp.

Boness, D. J., W. D. Bowen, and O. T. Oftedal. in press. Evidence from time-depth recorders of a foraging cycle during lactation in a small phocid, the harbor seal. Behav. Ecol. Soc.

Boveng, P. 1988. Status of Pacific harbor seal population on the U.S. west coast. Admin. Rep. LJ-88-06, Southwest Fish. Center, Natl. Mar. Fish. Serv. 43 pp.

Boveng, P., D. P. DeMaster, and B. S. Stewart. 1988. Dynamic response analysis. III. Consistency filter and application to four northern elephant seal colonies. Mar. Mamm. Sci. 4(3):210-222.

Boyd, I. L. and J. P. Croxall. 1992. Diving behavior of lactating fur seals. Can. J. Zool. 70:919-928.

Brown, R. F. 1986. Assessment of pinniped populations in Oregon. Processed Report, Natl. Mar. Fish. Serv., Northwest and Alaska Fisheries Center, Seattle, Washington.

Brown, R. F. and B. R. Mate. 1983. Abundance, movements, and feeding habits of harbor seals, *Phoca vitulina*, at Netarts and Tillamook Bay, Oregon. Fish. Bull. 81:291-302.

Brueggeman, J. J. (ed.). 1990. Oregon and Washington marine mammal and seabird surveys: information synthesis and hypothesis formulation. Final report prepared by Envirosphere Company, Bellevue, Washington, and Ecological Consulting, Inc., Portland, Oregon, for the Minerals Management Service, Pacific OCS Region. OCS Study MMS 89-0030. 374 pp.

Calambokidis, J., K. Bowman, S. Carter, J. Cubbage, P. Dawson, T. Fleischner, J. Schuett-Hames, J. Skidmore, and B. Taylor. 1978. Chlorinated hydrocarbon concentrations and the ecology and behavior of harbor seals in Washington State waters. Evergreen State College, Olympia, Washington. 121 pp.

Calambokidis, J., S. M. Speich, J. Peard, G. H. Steiger, J. C. Cubbage, D. M. Fry, and L. J. Lowenstine. 1985. Biology of Puget Sound marine mammals and marine birds: population health and evidence of pollution side effects. NOAA Tech. Memo. NOS OMA 18. 53 pp.

Calambokidis, J., G. H. Steiger, J. R. Evans, and S. J. Jeffries. 1991. Censuses and disturbance of harbor seals at Woodard Bay and recommendations for protection. Final report to Washington Dept. Nat. Resources, Olympia, Washington. 45 pp.

Caraco, T. 1979. Time budgeting and group size: a test of the theory. Ecol. 60:618-627.

da Silva, J. and J. M. Terhune. 1988. Harbor seal grouping as an anti-predator strategy. Anim. Behav. 36:1309-1316.

Day, R. W. and G. P. Quinn. 1989. Comparisons of treatments after an analysis of variance in ecology. Ecol. Monogr. 59(4):433-463.

DeLong, R. L. and B. S. Stewart. 1991. Diving patterns of northern elephant seals bulls. Mar. Mamm. Sci. 7(4):369-384.

DeLong, R. L., B. S. Stewart, and R. D. Hill. 1992. Documenting migrations of northern elephant seals using day length. Mar. Mamm. Sci. 8(2):155-159.

Eckstein, R. G., T. F. O'Brien, O. J. Rongstad, and J. G. Bollinger. 1979. Snowmobile effects on movements of white-tailed deer: a case-study. Envir. Conserv. 6(1):45-51.

Everitt, R. D., C. H. Fiscus, and R. L. Delong. 1980. Northern Puget Sound marine mammals. Interagency Energy/Environment Resource and Development Program Report, EPA-600/7-80-139. 134 pp.

Fay, F. H., B. P. Kelly, P. H. Gehnrich, J. L. Sease, and A. A. Hoover. 1986. Modern populations, migrations, demography, trophics, and historical status of the Pacific Walrus. NOAA/OCSEAP, Envir. Assess. Alaskan Cont. Shelf, Final Rep. Prin. Invest. 37:231-376. NTIS PB87-107546.

Fisher, H. D. 1952. The status of the harbour seal in British Columbia, with particular reference to the Skeena River. Bull. Fish. Res. Board Can. No. 93. 58 pp.

Fisher, H. D. 1954. Delayed implantation in the harbour seal, *Phoca vitulina l.* Nature. 173(4410):879-880.

Flaherty, C. F. and S. Stark. 1982. Harbor porpoise (*Phocoena phocoena*) assessment in "Washington Sound". Final report to NOAA, NMFS, National Marine Mammal Laboratory, Seattle, Washington. 84 pp.

Freddy, D. J., W. M. Bronaugh, and M. C. Fowler. 1986. Responses of mule deer to disturbance by persons afoot and snowmobiles. Wildl. Soc. Bull. 14(1):63-68.

Gentry, R. L. and G. L. Kooyman. 1986. Fur Seals: Maternal strategies on land and at sea. Princeton University Press, New Jersey.

Gerrodette, T. 1988. Dynamic response analysis. II. Evaluation of Dynamic response analysis in a simulated no-harvest case. Mar. Mamm. Sci. 4(3):196-209.

Gerrodette, T. and W. G. Gilmartin. 1990. Demographic consequences of changed pupping and hauling sites of the Hawaiian monk seal. Conserv. Biol. 4(4):423-430.

Glockner-Ferrari, D. A. and M. J. Ferrari. 1985. Individual identification, behavior, reproduction, and distribution of humpback whales, *Megaptera novaeangliae*, in Hawaii. MMC-83/06. Rep for Mar. Mamm. Comm. NTIS PB85-200772.

Goodman, D. 1988. Dynamic response analysis. I. Qualitative estimation of stock status relative to maximum net productivity level from observed dynamics. Mar. Mamm. Sci. 4(3):183-195.

Harvey, J. T. 1987. Population dynamics, annual food consumption, movements, and dive behaviors of harbor seals, *Phoca vitulina richardsi*, in Oregon. Ph.D. Dissertation, Oregon State University, 177 pp.

__________ 1989. Assessment of errors associated with harbour seal (*Phoca vitulina*) faecal sampling. J. Zool. (London) 218:101-111.

Harvey, J. T., R. F. Brown, and S. J. Jeffries. 1990. Abundance and distribution of harbor seals (*Phoca vitulina*) in Oregon, 1975 - 1983. Northwestern Nat. 71:65-71.

Huber, H., S. J. Jeffries, R. B. Brown, and R. D. DeLong. 1992. Abundance of harbor seals (*Phoca vitulina richardsi*) in Washington and Oregon, 1992. 1992 annual report to the MMPA Assessment Program, Office of Protected Resources, NMFS, NOAA, Silver Spring, Maryland 20910. 19 pp.

Ilmer, R. H. and H. R. Sarber. 1947. Harbour seals and sea lions in Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep. 28.

Jeffries, S. J. 1986. Seasonal movements and population trends of harbor seals (*Phoca vitulina richardsi*) in the Columbia River and adjacent waters of Washington and Oregon: 1976-1982. Report to the U.S. Marine Mammal Commission. Contract no. MM2079357-5. 41 pp.

Jeffries, S. J. and M. L. Johnson. 1987. Population status and condition of the harbor seal (*Phoca vitulina richardsi*) in the waters of the state of Washington: 1975-1980. Report to the U.S. Mar. Mamm. Comm. Contract no. MM7ACO30. 70 pp.

Jeffries, S. J., R. F. Brown, and J. T. Harvey. 1993. Techniques for capturing, handling and marking harbour seals. Aquatic Mamm. 19(1):21-25.

Johnson, B. W. 1977. The effects of human disturbance on a population of harbor seals. p. 422-431. In: Environmental assessment of the Alaskan continental shelf. Annul. Rep. Princ. Invest. Vol. 1. U.S. Dep. Comm. NOAA/OCSEAP. NTIS PB-280934/1.

Johnson, M. L. and S. J. Jeffries. 1983. Population biology of the harbor seal (*Phoca vitulina richardsi*) in the waters of the state of Washington. Report to the U.S. Mar. Mamm. Comm. MMC-76/25. 53 pp.

King, J. E. 1983. Seals of the world. Comstock publishing associates, Ithaca, New York. 240 pp.

Kooyman, G. L., M. A. Castellini, R. W. Davis, and R. A. Maue. 1983. Aerobic diving limits of immature Weddell seals. J. Comp. Physiol. 151:171-174.

Kooyman, G. L., Y. Cherel, Y. Le Maho, J. P. Croxall, P. H. Thorson, V. Ridoux, and C. A. Kooyman. 1992. Diving behavior and energetics during foraging cycles in King Penguins. Ecol. Monog. 62(1):143-163.

Kroll, A. M. 1993. Haul out patterns and behavior of harbor seals, *Phoca vitulina*, during the breeding season at protection island, Washington. M.S. Thesis, Univ. of Washington. 142 pp.

Lamont, M. 1995. Genetic substructure of Pacific harbor seals (*Phoca vitulina richardsi*) off Washington, Oregon, and California. M.S. Thesis, California State University, Stanislaus. 43 pp.

Le Boeuf, B. J., Y Naito, A. C. Huntley, and T. Asaga. 1989. Prolonged, continuous, deep diving by northern elephant seals. Can. J. Zool. 67:2514-2519.

Loughlin, T. R., J. L. Bengtson, and R. L. Merrick. 1987. Characteristics of feeding trip of female northern fu seals. Can. J. Zool. 65:2079-2084.

Lydersen, C. and M. O. Hammil. 1993. Diving in ringed seal (*Phoca hispida*) pups during nursing period. Can. J. Zool. 71:991-996.

MacArthur, R. A., V. Geist, and R. H. Johnston. 1982. Cardiac and behavioral responses of mountain sheep to human disturbance. J. Wildl. Manage. 46(2):351-358.

Mansfield, A. W. 1967. Distribution of the harbor seal, *Phoca vitulina* Linnaeus, in Canadian arctic waters. J. Mammal. 48(2):249-257.

Mate, B. R. 1980. Workshop on marine mammal-fisheries interactions in the northeastern Pacific. U.S. Dep. Comm., Natl. Tech. Info. Serv. Publ. No. PB80-1751144. Springfield, VA. 48 pp.

Miller, E. J. 1989. Distribution and behavior of Dall's porpoise (*Phocoenoides dalli*) in Puget Sound, Washington. M.S. Thesis, Univ. of Washington. 97 pp.

Moen, A. N., S. Whittemore, and B. Buxton. 1982. Effects of disturbance by snowmobiles on heart rate of captive white-tailed deer. N.Y. Fish and Game J. 29(2):176-183.

Moss, J. 1992. Environmental and biological factors that influence harbor seal (*Phoca vitulina richardsi*) haul out behavior in Washington and their consequences for the design of population surveys. M.S. Thesis, Univ. of Washington. 122 pp.

Murphy, E. C. and A. A. Hoover. 1981. Research study of the reactions of wildlife to boating activity along Kenai fjords coastline. Final Rep. to Nat. Park Serv. Anchorage, Alaska. 125 pp.

Newby, T. C. 1973. Observations on the breeding behavior of the harbor seal in the State of Washington. J. Mammal. 54:540-543.

Olesiuk, P. F., M. A. Bigg, and G. M. Ellis. 1990. Recent trends in the abundance of harbor seals, *Phoca vitulina*, in British Columbia. Can. J. Fish. Aquat. Sci. 47: 992-1003.

Pitcher, K. W. 1977. Population productivity and food habits of harbor seals in the Prince William Sound-Copper River Delta area, Alaska. Report to the U.S. Marine Mammal Commission, Contract No. MM5AC011.

___________ 1989. Harbor seal trend count surveys in southern Alaska, 1988. Final Rept. by Alaska Dept. Fish and Game to U.S. Marine Mammal Commission, Washington D.C. 15pp.

___________ 1990. Major decline in number of harbor seals, *Phoca vitulina richardsi*, on Tugidak Island, Gulf of Alaska. Mar. Mamm. Sci. 6(2):121-134.

Pitcher, K. W. and D. C. McAllister. 1981. Movements and haul-out behavior of radio-tagged harbor seals, *Phoca vitulina*. Can. Field Nat. 95(3):292-297.

Raum-Suryan, K. L. 1995. Distribution, abundance, habitat use, and respiration patterns of harbor porpoise (*Phocoena phocoena*) off the northern San Juan Islands, Washington. M.S. Thesis, Moss Landing Marine Laboratories, San Jose State University. 79 pp.

Renouf, D. and J. W. Lawson. 1986. Harbor seal vigilance: watching for predators or mates? Biol. of Behav. 11:44-49.

Richardson, W. J., C. R. Greene Jr., C. I. Malme, and D. H. Thomson. 1991. Effects of noise on marine mammals. LGL Ecological Research Associates Inc. report TA834-1, Bryan TX. 419 pp.

Richens, V. B. and G. R. Lavigne. 1978. Response of white-tailed deer to snowmobiles and snowmobile trails in Maine. Can. Field-Nat. 92(4):334-344.

Salden, D. R. 1988. Humpback whale encounter rates offshore of Maui, Hawaii. J. Wildl. Manage. 52(2):301-304.

Scheffer, V. B. 1967. Newborn harbor seals on the Pribilof Islands, Alaska. Murrelet 48(2):44.

____________ 1974. February birth of Mexican harbor seals. Murrelet 55(3):44.

Shaughnessy, P. D. and F. H. Fay. 1977. A review of the taxonomy and nomenclature of North Pacific harbor seals. J. Zool. Lond. 182:385-419.

Slater, S. E. and H. Markowitz. 1983. Spring population trends in *Phoca vitulina richardsi* in two central California coastal areas. Calif. Fish and Game 69(4):217-226.

Spalding, D. J. 1964. Comparative feeding habits of the fur seal, sea lion and harbour seal on the British Columbia coast. Bull. Fish. Res. Board Can. No. 146. 52 pp.

Stasko, A. B., R. M. Horrel, and A. D. Hasler. 1976. Coastal movements of adult Fraser River salmon (*Oncorhynchus nerka*) observed by ultrasonic tracking. Trans. am. Fish. Soc. 105:64-74.

Stein, J. L. 1989. Reproductive parameters and behavior of mother and pup harbor seals, *Phoca vitulina richardsi*, in Grays Harbor, Washington. M.S. Thesis, San Francisco State Univ. 110 pp.

Stewart, B. S. and P. K. Yochem. 1983. Radio telemetry studies of hauling patterns, movements, and site fidelity of harbor seals (*Phoca vitulina richardsi*) at San Nicolas and San Miguel Islands, California, 1982. Hubbs-Sea World Research Inst., Tech. Rep. 83-152:1-56.

Studd, M., R. D. Montgomerie, and R. J. Robertson. 1983. Group size and predator surveillance in foraging house sparrows (*Passer domesticus*). Can. J. Zool. 61:226-231.

Temte, J. L. 1985. Photoperiod and the timing of pupping in the Pacific harbor seal (*Phoca vitulina richardsi*) with notes on reproduction in Northern fur seals and Dall's porpoises. M.S. Thesis, Oregon State Univ. 147 pp.

Temte, J. L. 1993. Latitudinal variation in the birth timing of captive California sea lions and other captive North Pacific pinnipeds. Fish. Bull. 91(4):710-717.

Temte, J. L., M. A. Bigg, and O. Wiig. 1991. Clines revisited: the timing of pupping in the harbour seal (*Phoca vitulina*). J. Zool., Lond. 224:617-632.

Terhune, J. M. 1985. Scanning behavior of harbor seals on haul-out sites. J. Mamm. 62(2):392-395.

Terhune, J. M. and M. Almon. 1983. Variability of harbour seal numbers on haul-out sites. Aquat. Mamm. 10:71-78.

Thompson, P. M. 1989. Seasonal changes in the distribution and composition of the common seal (*Phoca vitulina*) haul-out groups. J. Zool. 217:281-294.

Thompson, P. M. and D. Miller. 1990. Summer foraging activity and movements of radio-tagged common seals (*Phoca vitulina.* L.) in the Moray Firth, Scotland. J. Appl. Ecol. 27:492-501.

Torok, M. L. 1994. Movements, daily activity patterns, dive behavior, and food habits of harbor seals (*Phoca vitulina richardsi*) in San Francisco Bay, California. M.S. Thesis, California State University, Stanislaus. 88 pp.

Williams, T. D., A. Kato, J. P. Croxall, Y. Naito, D. R. Briggs, S. Rodwell, and T. R. Barton. 1992. Diving pattern and performance in nonbreeding Gentoo Penguins (*Pygoscelis papua*) during winter. Auk 109(2):223-234.

Yochem, P. K., B. S. Stewart, R. L. DeLong, and D. P. DeMaster. 1987. Diel haul-out patterns and site fidelity of harbor seals (*Phoca vitulina richardsi*) on San Miguel Island, California, in autumn. Mar Mamm. Sci., 3(4):323:332.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Englewood Cliffs, N.J., 718 pp.

Table 1. Recovery of harbor seals following harassments at Puffin Island, Clements Reef, and Skipjack Island, northern San Juan Islands, Washington.

	Puffin Island (n = 29)	Clements Reef (n = 29)	Skipjack Island (n = 11)
Full Recovery			
% of recoveries	24%	52%	45%
no. before low tide	5	10	5
no. after low tide	2	5	0
Partial Recovery			
% of recoveries	28%	34%	18%
no. before low tide	4	1	0
no. after low tide	4	9	2
No Recovery			
% of recoveries	41%	7%	36%
no. before low tide	2	0	0
no. after low tide	10	2	4
No Chance to Recover			
% of recoveries	7%	7%	0
no. before low tide	0	0	0
no. after low tide	2	2	0

Table 2. Mean, standard error (SE), and sample size (n) of distances (m) at which powerboats disturbed (detection, alarm, harassment) harbor seals ashore before and after an initial harassment at Puffin Island and Clements Reef. Vessel approach to haul-out site is categorized as underway fast, underway slow, and drifting.

	Detection						Alarm						Harassment					
	Before			After			Before			After			Initial			Subsequent		
Boat Speed	**mean**	SE	n	**mean**	SE	n	**mean**	SE	n	**mean**	SE	n	**mean**	SE	n	**mean**	SE	n
Puffin Island																		
underway fast	**333**	36.67	6	**102**	19.78	2	-	-	-	-	-	-	-	-	-	-	-	-
underway slow	**230**	24.33	14	**154**	30.77	5	**171**	-	1	**138**	-	1	**129**	22.04	5	**72**	22.36	4
drifting	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Clements Reef																		
underway fast	**260**	15.59	4	**299**	51.41	6	-	-	-	**194**	93.68	3	**156**	68.04	3	**120**	15.50	2
underway slow	**265**	40.64	9	**167**	43.15	9	**106**	52.79	3	**80**	23.50	2	**176**	42.50	2	**67**	21.31	8
drifting	**332**	-	1	**82**	23.03	9	-	-	-	**134**	40.97	4	**129**	80.50	2	**65**	11.50	7

Table 3. Radio frequency of flipper or head-mounted transmitter, plastic flipper tag number, capture date and location, measurements, age, and sex of thirteen harbor seals captured at Clements Reef and Puffin Island, San Juan Islands, Washington, during 1992.

Transmitter Frequency[1] Flipper (Head)	Flipper Tag No.	Capture Date	Capture Location	Length (cm)	Weight (kg)	Age	Sex
014	721	16 June	Clements Reef	139	62.5	adult	M
(264)	717	"	"	153	85.0	adult	"
530	723	"	"	119	52.0	subadult	"
(674)	718	"	"	143	61.5	"	"
810	722	"	"	148	69.5	"	"
954	719	"	"	142	69.5	"	"
044	733	2 July	Puffin Island	163	99.0	adult	"
385	728	"	"	140	80.0	"	"
644	729	"	"	140	82.5	"	"
(155)	738	3 July	Clements Reef	108	40.6	subadult	"
(165)	737	"	"	142	77.3	"	"
505	739	"	"	97	29.0	"	"
(915)	736	"	"	151	104.0	adult	"

[1]Frequencies were 164-165 MHz. Seals are referred to by transmitter frequency in text.

Table 4. Haul-out sites used by radio-tagged harbor seals within the northern San Juan Islands, Washington (21 June to 11 September 1992).

Seal #	Capture Location	June		July					August				September	
		21	29	9	10	14	28	30	11	12	25	26	9	11
014	CR		FI											
044	PI			PI		PI	PI	PI	PI				PI	
155	CR			CR		CR			CR		CR	CR	CR	
165	CR			SB			SB		SB	SB	SB	SB	SB	SB
264	CR			CR		CR			ER	ER				
385	PI			PI	PI	PI	PI		PI				PI	MI
505	`CR					CR	CR	CR		SB				
530	CR		CR	CR				CR			FI	FI		FI
644	PI			BI	BI	BI	BI		BI					
674	CR	CR	CR			CR	CR	CR		CR		CR		
810	CR		CR			SB								WR
915	CR			CR	CR	CR		CR	CR					
954	CR	CR	CR	CR		CR	CR							

BI = Barnes Island, CR = Clements Reef, ER = Ewing Island Reef, FI = Finger Island, MI = Matia Island, PI = Puffin Island, SB = Skipjack/Bare Islands, WR = White Rock.

Table 5. A summary of tracking effort (hours) for five harbor seals with head-mounted radio transmitters, northern San Juan Islands, Washington, 22 June - 4 September 1992 (C = contact, receive signal, but did not track, NC = no contact, HO = seal is on haul-out site).

Date	Seal #155		Seal #165		Seal #264		Seal #674		Seal #915	
	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal	Diurnal	Nocturnal
22 June						2.0		C		
14 July	0.5		NC		C		C		C	
15		NC		NC		NC		C	5.0	0.25
17		NC		3.0						C
18						C		0.5		
20	NC		C		NC		1.5		NC	
21								C		3.0
22	C		2.5	1.0	C					
24	NC		C		2.5		C		NC	
31	HO		C		1.0		1.25		C	
08 Aug	lost transmitter		C		C		C		C	
15						0.5		5.25	lost transmitter ?	
16			3.0							
18				C		3.0		C		
24			C		4.0		C			
27				4.0	NC			NC		
28			HO		C		2.0	0.25		
04 Sept				2.5		NC		NC		
total hrs	0.5	0	5.5	10.5	7.5	5.5	4.75	6.0	5.0	3.25

Table 6. Mean, standard error (SE), and sample sizes (n) of duration of dives and surfacings for activity states of harbor seals with head-mounted radio transmitters tracked off the northern San Juan Islands, Washington, 22 June to 4 September 1992. Lines above means indicate no significant ($p > 0.05$) difference.

Seal No.	Overall			Milling			Traveling			Nearshore			Resting		
	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE	n	mean	SE	n
Duration of Dives															
165	**3.18**	0.08	212	**4.00**	0.14	47	**3.16**	0.23	25	**2.87**	0.16	58	**2.88**	0.12	73
264	**4.50**	0.20	144	**6.22**	0.26	42	**3.53**	0.16	48	**3.59**	0.25	23	-	-	-
674	**3.22**	0.15	157	**4.58**	0.26	39	**3.57**	0.15	66	**1.52**	0.22	50	-	-	-
915	**4.57**	0.17	78	**4.79**	0.17	68	-	-	-	**3.02**	0.44	10	-	-	-
Duration at Surface															
165	**0.57**	0.02	221	**0.66**	0.04	52	**0.61**	0.02	26	**0.52**	0.03	57	**0.46**	0.02	74
264	**0.83**	0.03	145	**1.20**	0.05	44	**0.61**	0.05	48	**0.63**	0.08	23	-	-	-
674	**0.60**	0.03	163	**0.72**	0.06	41	**0.62**	0.04	68	**0.47**	0.05	50	-	-	-
915	**0.88**	0.03	81	**0.88**	0.03	71	-	-	-	**0.88**	0.13	10	-	-	-

Table 7. Mean, standard error (SE), and sample size (n) for duration (min) of diurnal and nocturnal dives of harbor seals radio-tagged in the northern San Juan Islands, Washington, 22 June to 4 September 1992. Mean duration of dive is reported for overall and activity states.

	Diurnal			Nocturnal		
	mean	SE	n	**mean**	SE	n
Seal #165						
overall	**3.08**	0.03	83	**3.25**	0.10	130
Milling	**3.52**	.23	21	**4.38**	0.13	26
Traveling	-			**3.12**	0.25	23
Nearshore	**2.85**	0.2	46	-		
Resting	-			**2.88**	0.12	73
Seal #264						
overall	**5.12**	0.25	68	**3.95**	0.27	76
Milling	**6.21**	0.25	42	-		
Traveling	**3.60**	0.27	24	**3.45**	0.18	24
Nearshore	-			**3.58**	0.25	23
Seal #674						
overall	**2.47**	0.25	66	**3.65**	0.20	74
Milling	**4.62**	0.08	13	**4.55**	0.38	26
Traveling	**4.12**	0.20	22	**3.02**	00.20	36
Nearshore	**1.20**	0.23	40	**2.80**	0.38	10
Seal #915						
overall	**5.20**	0.27	36	**3.95**	0.18	39
Milling	**5.20**	0.27	36	**4.27**	0.18	29
Traveling	-			**3.03**	0.43	10

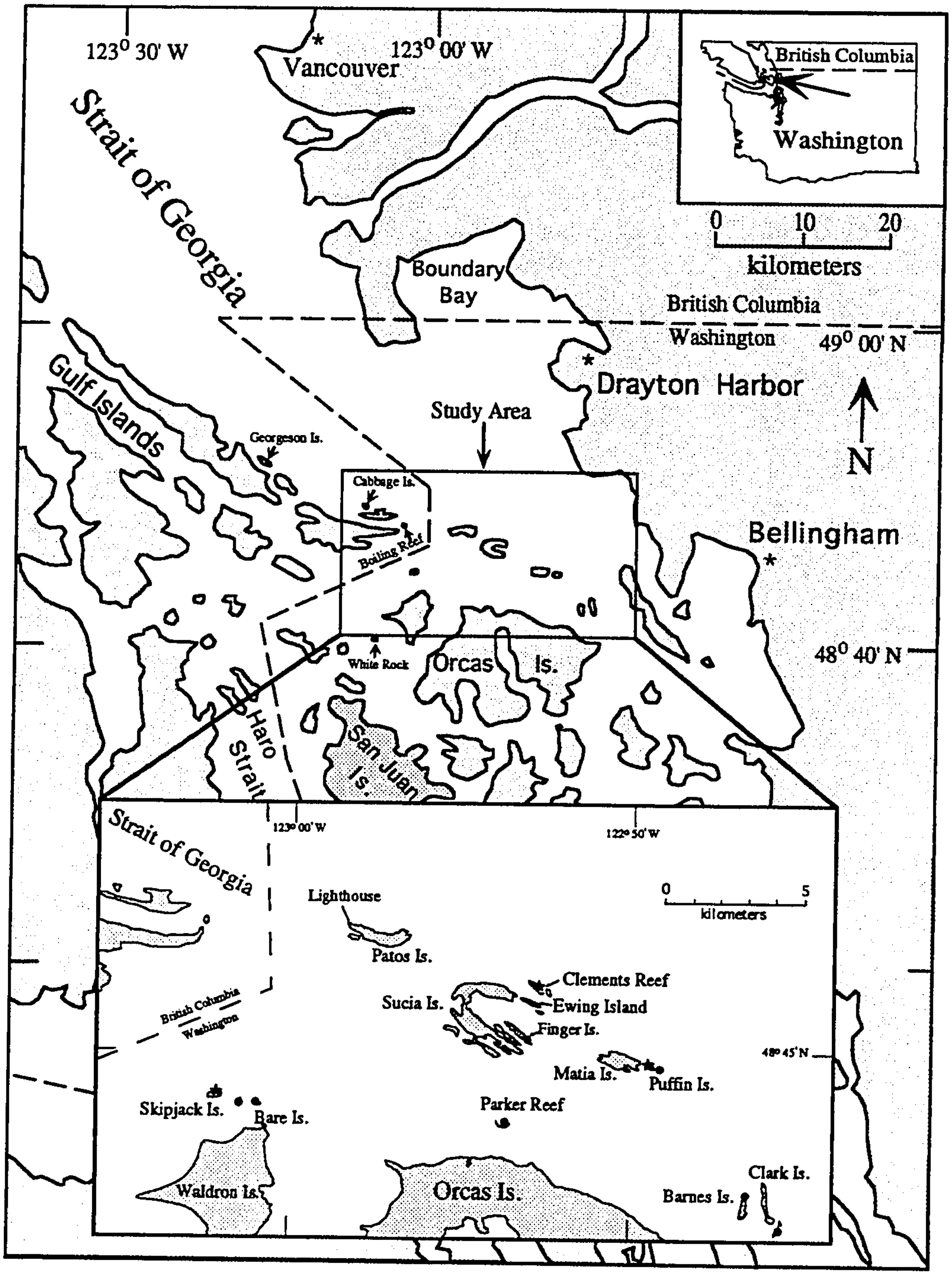

Figure 1. San Juan Islands (study area), Washington, Gulf Islands and Boundary Bay, British Columbia, Canada. Inset map indicates location of haul-out sites observed during shorebased surveys (★; 1991 and 1992) and haul-out sites surveyed biweekly for harbor seals with flipper-mounted radio transmitters (★and •; 1992).

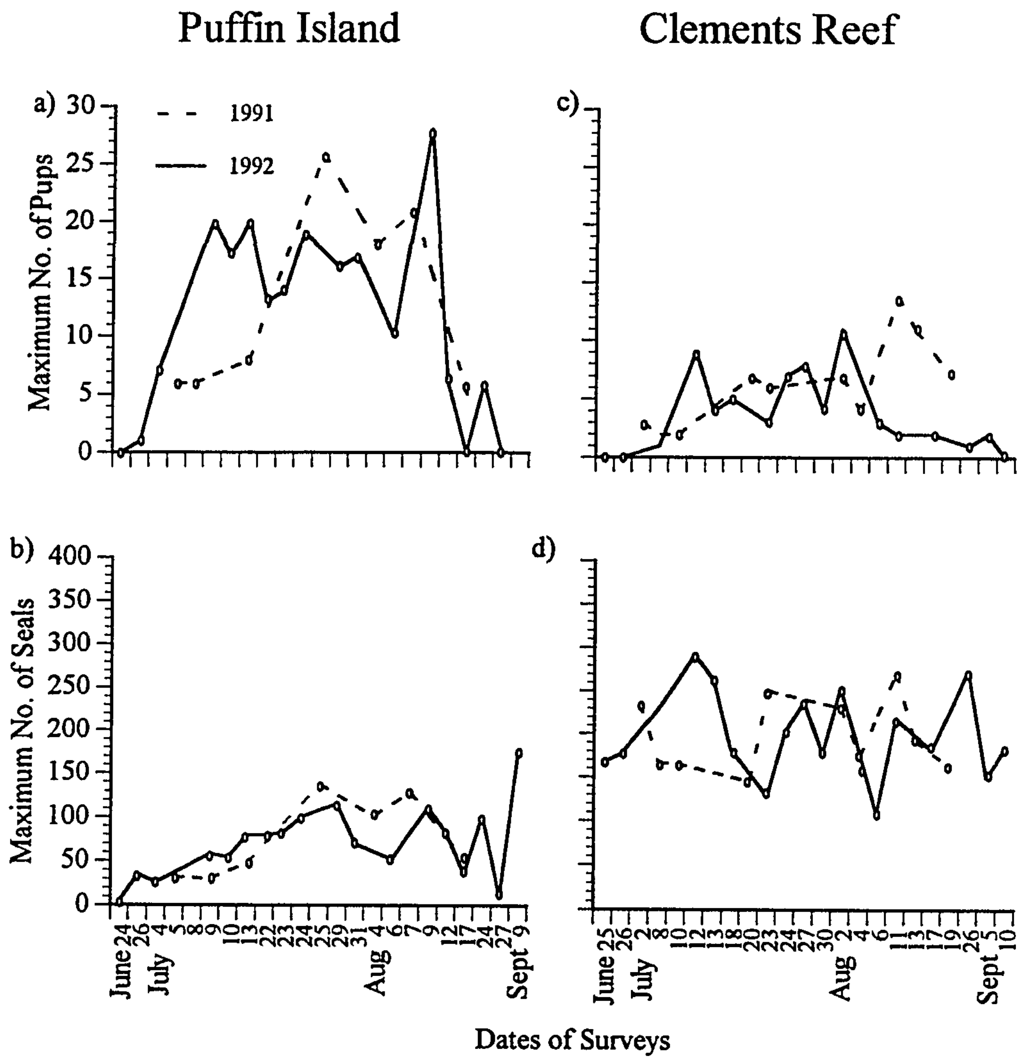

Figure 2. Maximum counts of harbor seal pups at Puffin Island (a) and Clements Reef (c). Maximum counts of adult and subadult harbor seals at Puffin Island (b) Clements Reef (d), northern San Juan Islands, Washington. Circles indicate dates of survey.

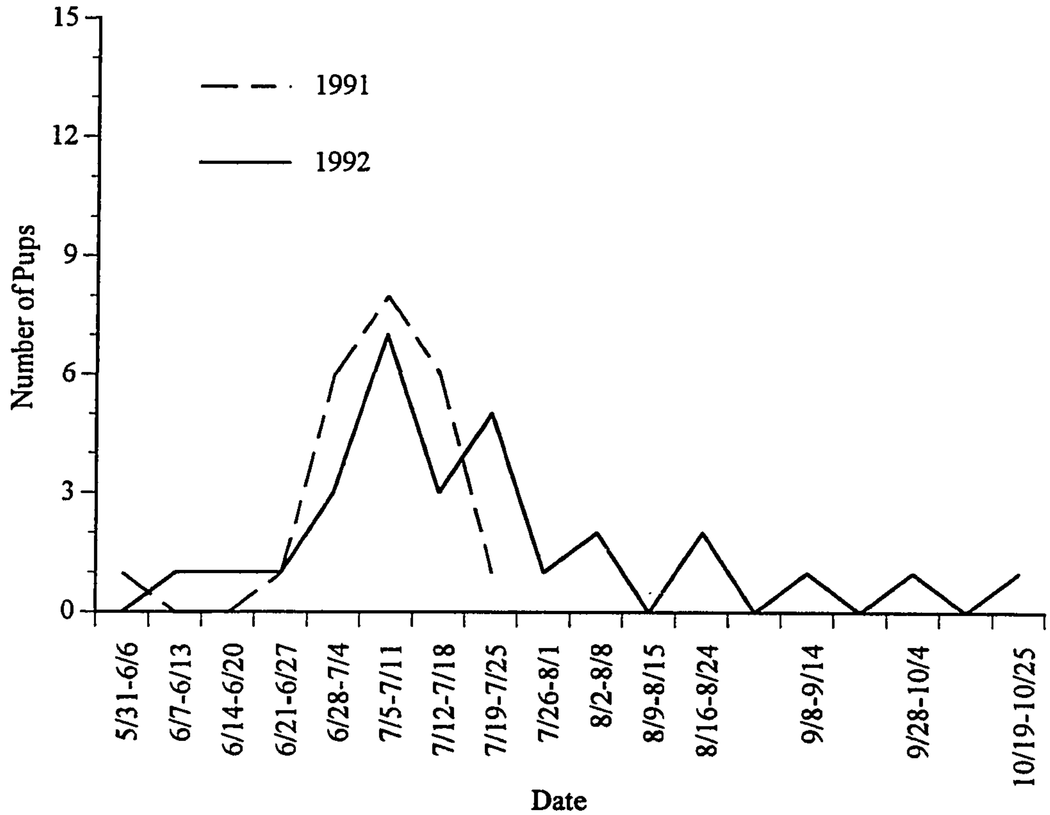

Figure 3. Arrival dates of full-term harbor seal pups at Wolf Hollow Wildlife Rehabilitation Centre on San Juan Island, Washington. Pups were from the San Juan Islands and Puget Sound.

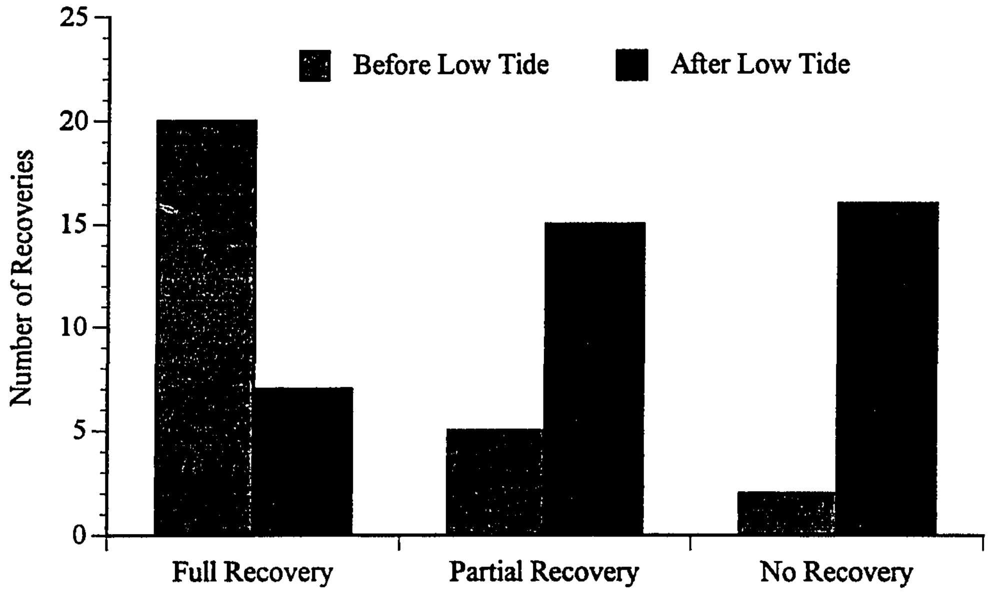

Figure 4. Extent of harbor seal recovery after a harassment, before and after low tide. Data for Puffin Island, Clements Reef, and Skipjack Island, Washingon, were pooled.

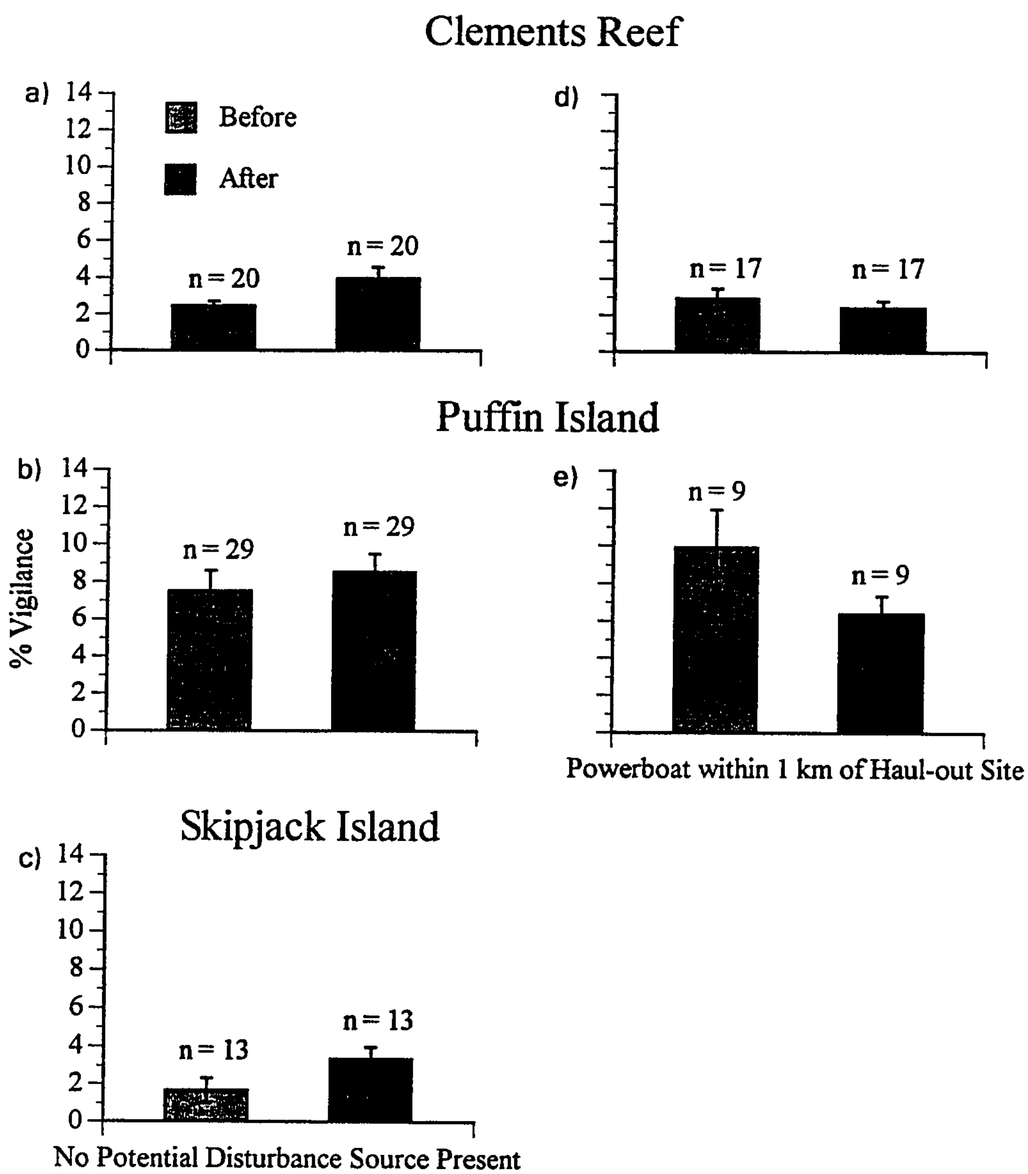

Figure 5. Mean percentage of harbor seals vigilant (± SE) before and after an initial harassment during a haul-out period at Clements Reef (a), Puffin Island (b), and Skipjack Island (c), Washington, when no potential disturbance source was within 1km of the haul-out site and at Clements Reef (d) and Puffin Island (e) when ≥ 1 powerboat was within 1 km of the haul-out site. Means among graphs are not comparable due to effect of unequal harbor seal group sizes.

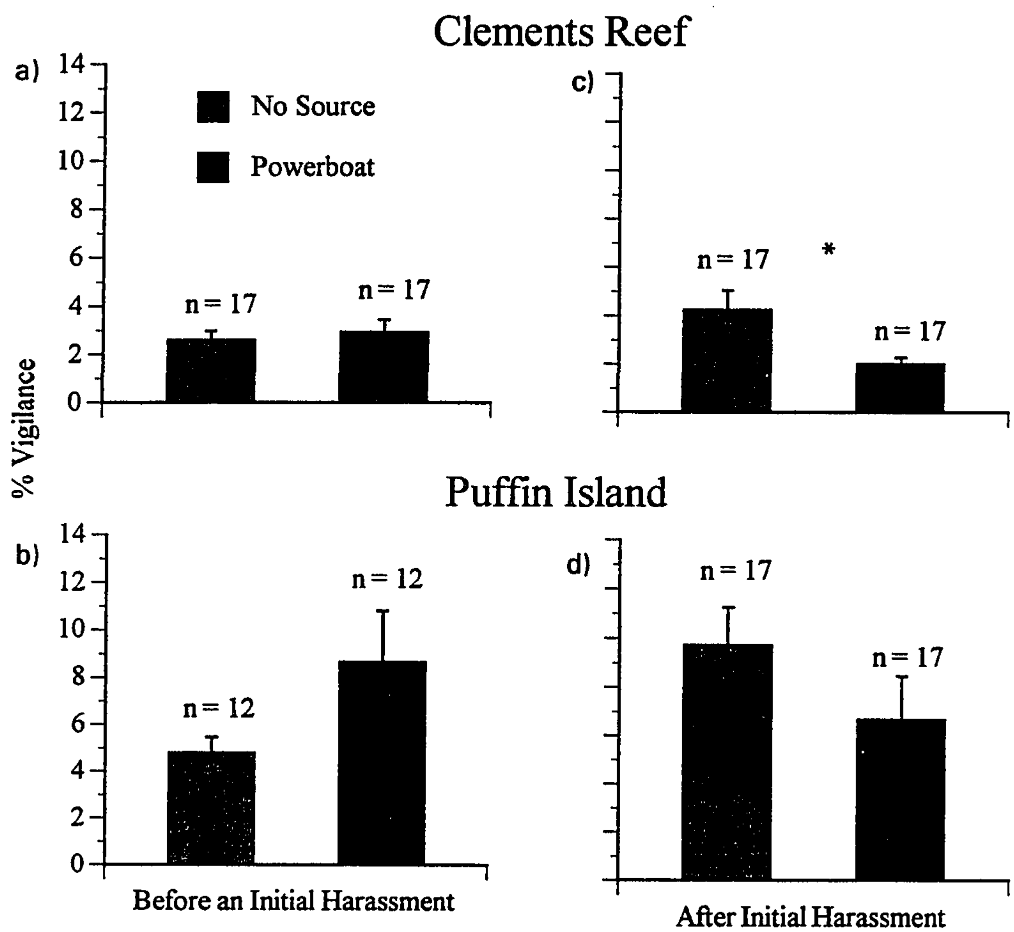

Figure 6. Mean percentage of harbor seals vigilant (± SE) before an initial harassment during a haul-out period at Clements Reef (a) and Puffin Island (b), and after an initial harassment at Clements Reef (c) and Puffin Island (d), Washington. Data included no potential disturbance source and ≥ 1 powerboat within 1 km of the haul-out site. An asterisk (*) indicates a significant ($p < 0.05$) difference. Means between graphs are not comparable due to the effect of unequal group sizes.

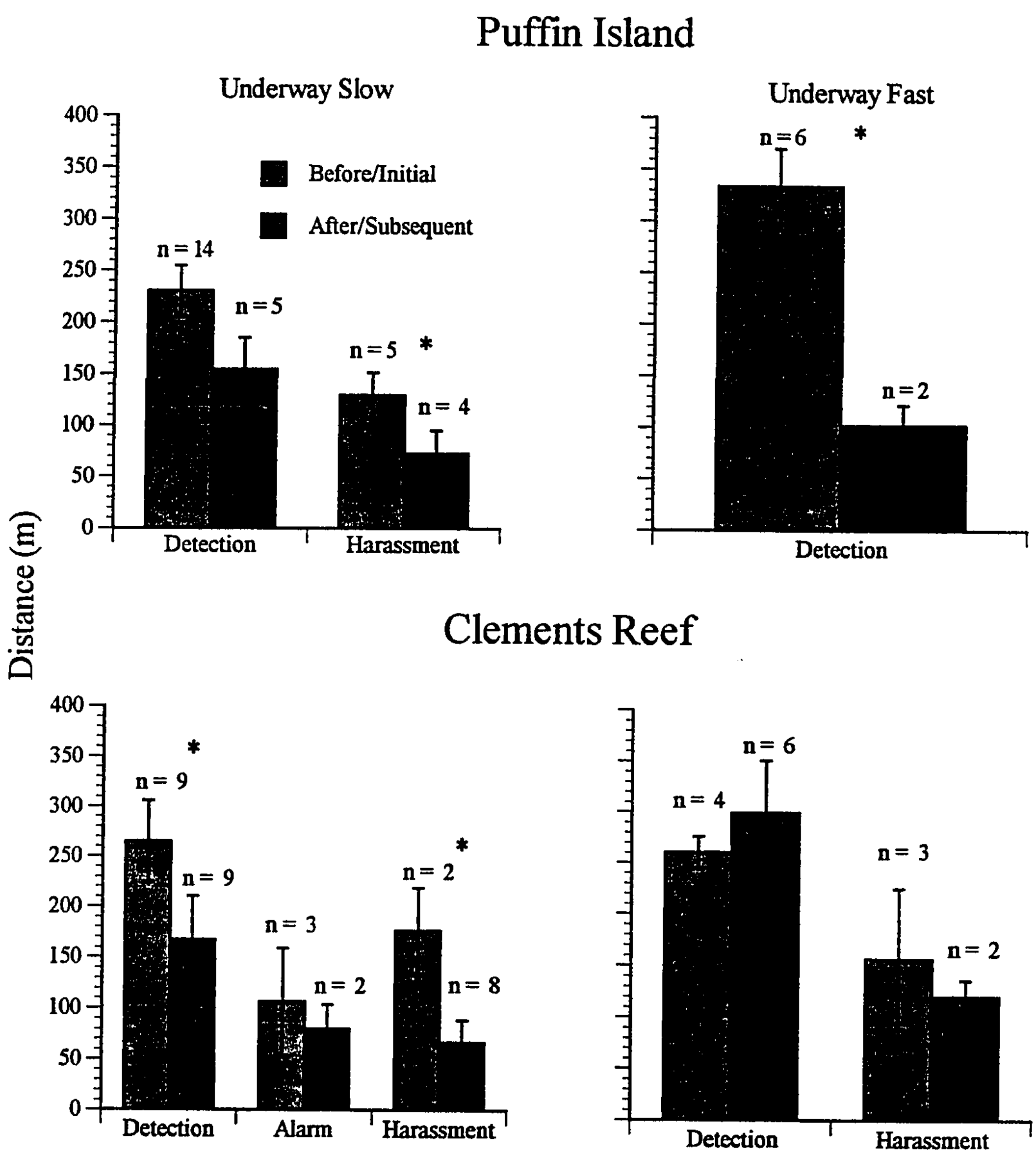

Figure 7. Mean distance (± SE) between harbor seals and powerboat for disturbances occurring before and after the initial harassment during a haul-out period. Data included a powerboat approaching a haul-out site underway slow and underway fast. An asterisk (*) indicates a significant ($p < 0.10$) difference between before/initial and after/subsequent data for that disturbance category.

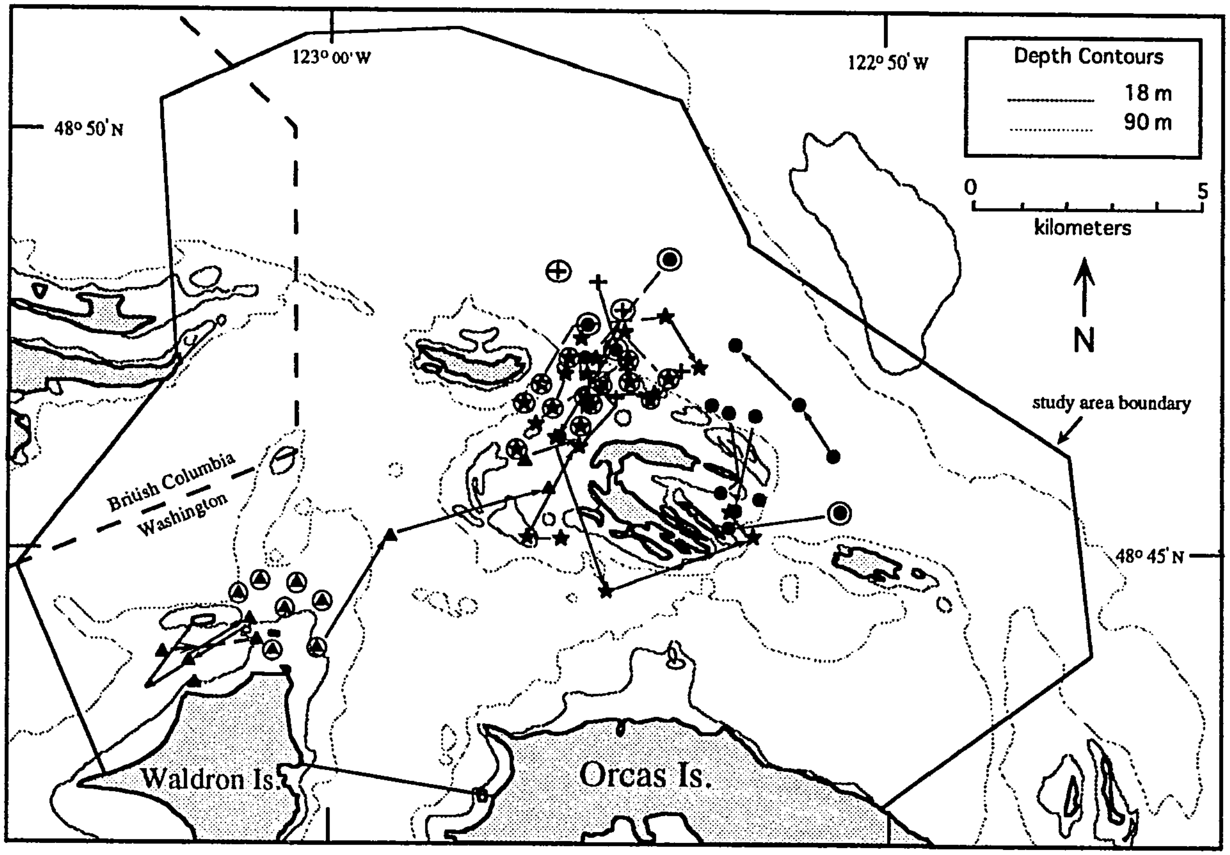

Figure 8. In-water locations of harbor seals #155 (■), #165 (▲), #264 (●), #674 (★), and #915 (+) tracked off the northern San Juan Islands, Washington, 22 June to 4 September 1992. A circle around a symbol indicates an approximate location (within a 1 km radius). Arrows and lines connect multiple locations obtained during a 5 hr tracking survey. Solid arrows indicate observed movements. Dashed lines indicate unknown movements between locations.

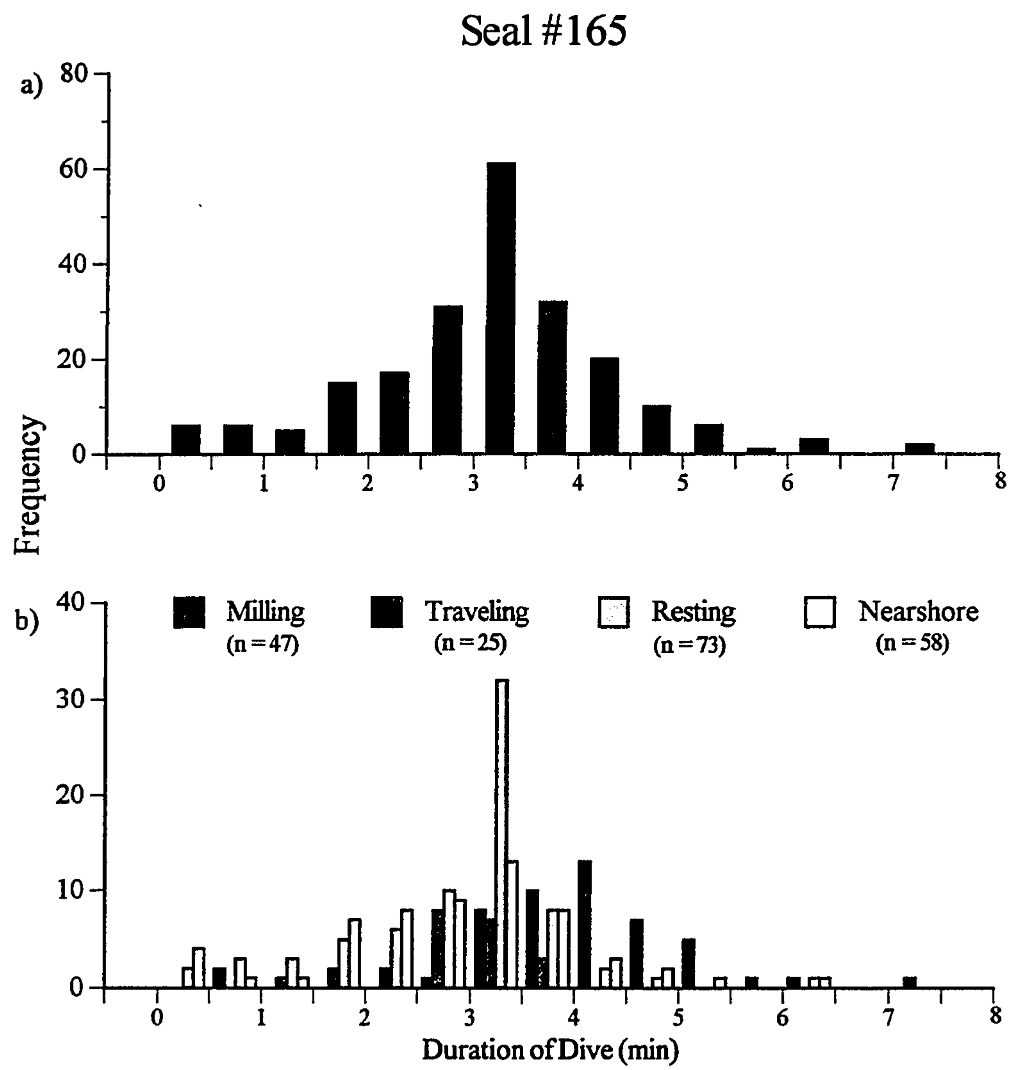

Figure 9. a) Frequency distribution of duration of dives (n = 215) for harbor seal #165. b) Frequency distribution of duration of dives for activity states of harbor seal #165. The seal was tracked off the northern San Juan Islands, Washington, 14 July to 4 September 1992.

Seal #674

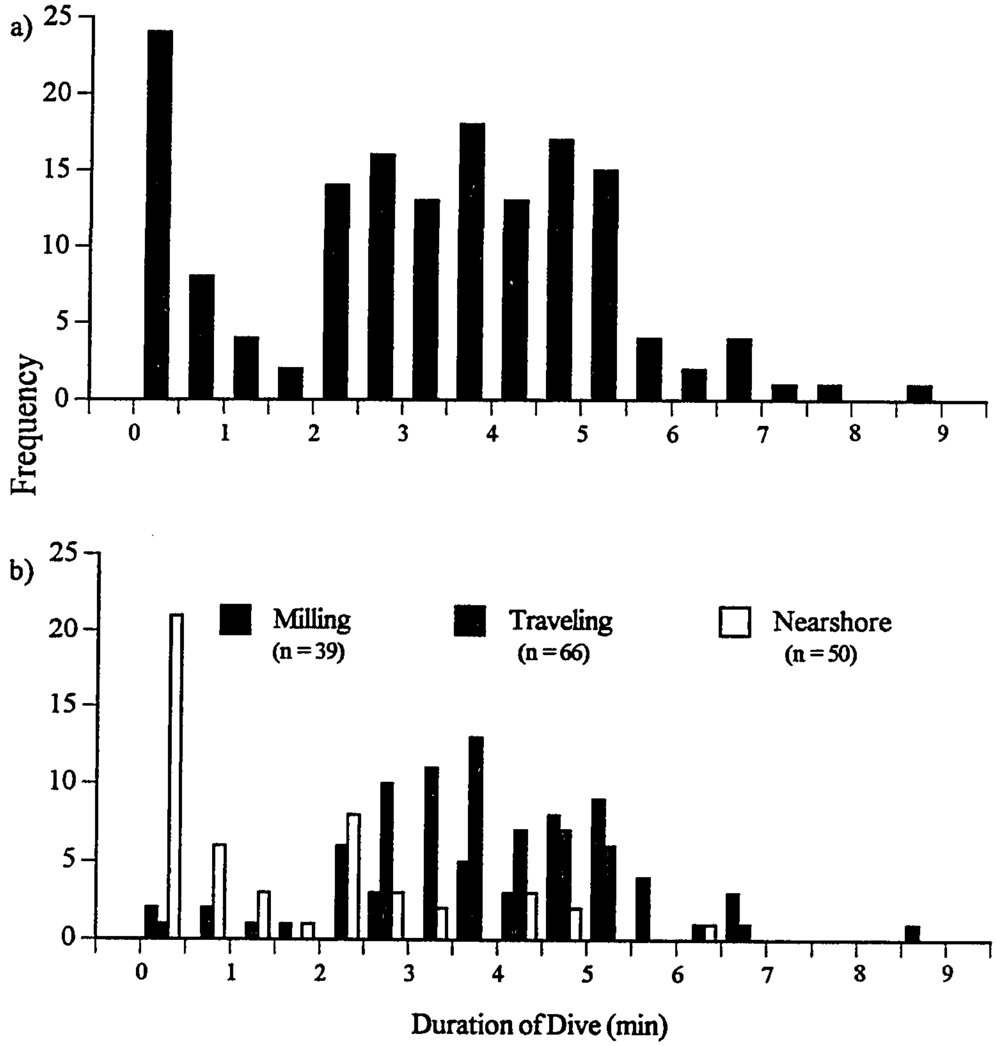

Figure 10. a) Frequency distribution of duration of dives (n = 157) for harbor seal #674. b) Frequency distribution of duration of dives for activity states of harbor seal #674. The seal was tracked off the northern San Juan Islands, Washington, 22 June to 4 September 1992.

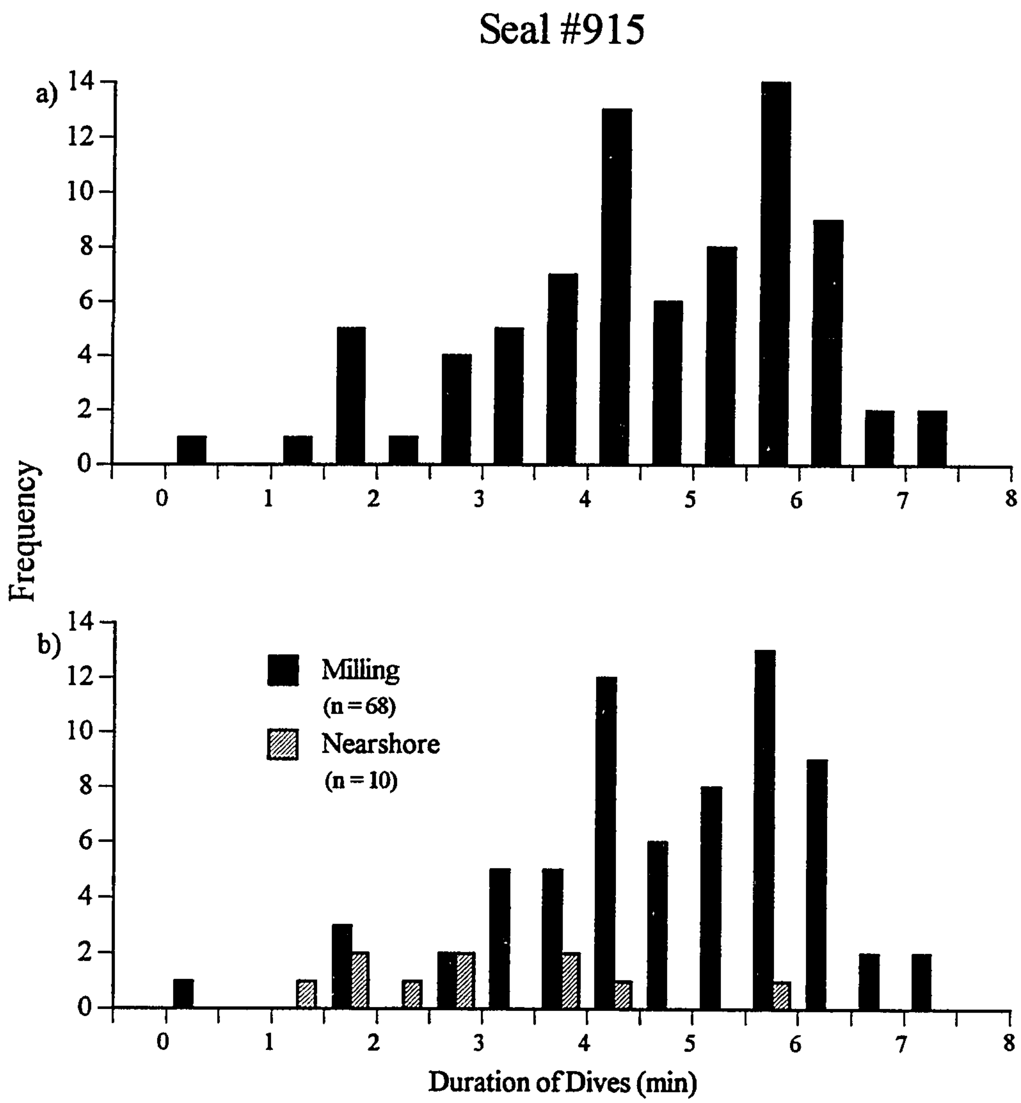

Figure 11. a) Frequency distribution of duration of dives (n = 78) for harbor seal #915. b) Frequency distribution of duration of dives for activity states of harbor seal #915. The seal was tracked off the northern San Juan Islands, Washington, 14 July to 8 August 1992..

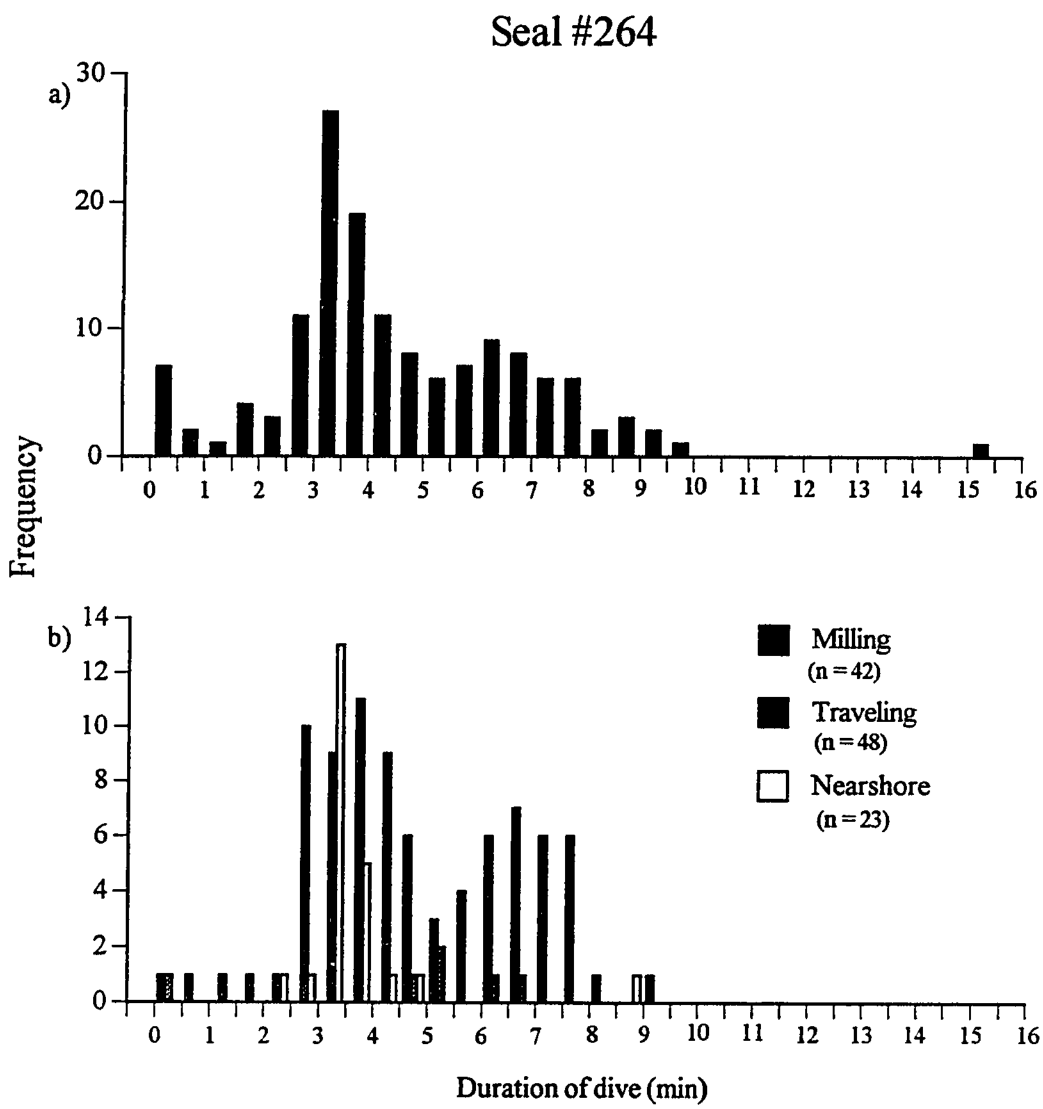

Figure 12. a) Frequency distribution of duration of dives (n = 144) for harbor seal #264. b) Frequency distribution of duration of dives for activity states of harbor seal #264. The seal was tracked off the northern San Juan Islands, Washington, 22 June to 4 September 1992.

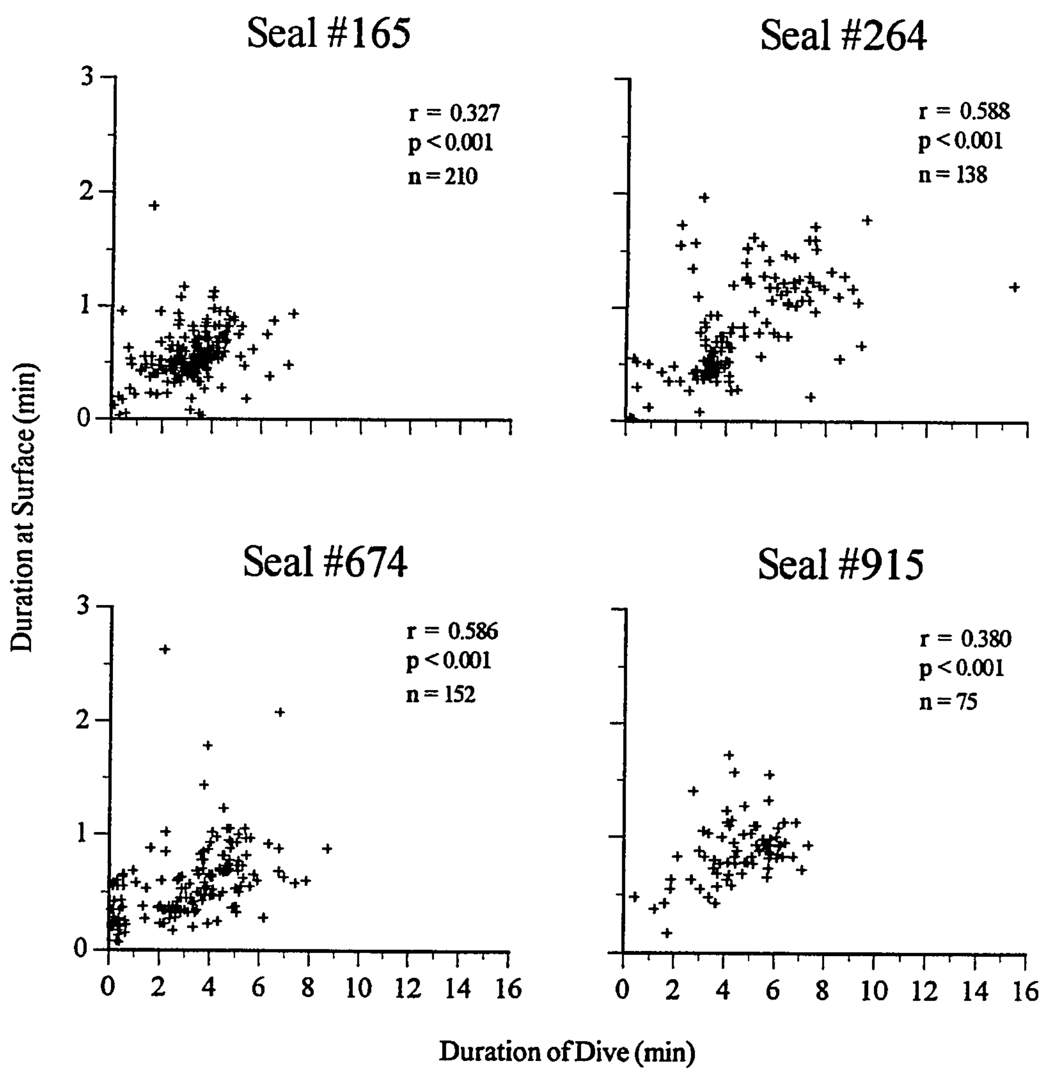

Figure 13. Scatter plots and correlation of duration of dive versus duration at surface for harbor seals tracked off the northern San Juan Islands, Washington, 22 June to 4 September 1992.