

GROWTH AND DEVELOPMENT IN
FREE-RANGING HARBOR SEAL
(*PHOCA VITULINA*) PUPS FROM
SOUTHERN BRITISH COLUMBIA, CANADA

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ABSTRACT

Harbor seals (*Phoca vitulina*) are small pinnipeds that are widely distributed throughout the temperate coastal regions of the Atlantic and Pacific oceans. We determined birth mass, neonatal growth rates, weaning age, and weaning mass of NE Pacific harbor seals (*P. v. richardsi*) during a capture-recapture study that spanned the nursing period (Sidney Island, British Columbia, Canada). Of 46 harbor seal pups initially captured, 28 were classified as newborns (*i.e.*, <24 h old). Mean body mass of newborns was $11.2 \pm \text{SE } 0.31$ kg. Pups were individually tagged and recaptured throughout the nursing period. Average daily mass gain during the nursing period was 394 ± 26 g. Mean birth mass of males did not differ significantly from females, although pups found with fetal pelage (lanugo) (21.4% of all newborns) were smaller at birth (9.8 ± 0.44 kg) than non-lanugo pups (11.6 ± 0.33 kg). Mean weaning mass was estimated at 23.6 ± 1.2 kg at a mean weaning age of $32 \text{ d} \pm 1.5 \text{ d}$. While birth and weaning masses differed little from the published data for offshore Sable Island harbor seals (*P. v. concolor*), British Columbia harbor seals are characterized by half the daily mass gain and a longer nursing period.

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Key words: harbor seal, *Phoca vitulina*, pup, birth, growth, nursing, weaning, development, British Columbia.

The harbor seal (*Phoca vitulina*) is a small pinniped comprising five subspecies, which are widely distributed throughout the temporal coastal regions of the northern hemisphere. This phocid species occupies numerous habitat types in both the Atlantic and Pacific oceans, with mother-pup pairs hauling out on sandy and rocky intertidal substrates, as well as log booms and other man-made structures (Bigg 1981). Although harbor seals have been extensively studied as a consequence of their relative abundance, small size and non-aggressive nature compared to many other pinnipeds, work has been restricted to a few areas. Like all phocids, harbor seals are iteroparous with a birth mass proportionately large relative to maternal mass (Scheffer and Slipp 1944, Bowen *et al.* 1992a). Harbor seal pups are particularly precocious, swimming immediately after birth and throughout the lactation period, unlike most other phocids which normally enter the sea only after weaning (Bishop 1967, Bigg 1969a, Newby 1973, Boulva and McLaren 1979, Lawson and Renouf 1985).

The timing of the pupping and breeding season for harbor seals varies widely within and between subspecies, perhaps reflecting regional differences in the seasonal abundance of prey that are important to the survival of weaned seal pups (Bigg 1969a, Bigg 1973, Temte *et al.* 1991). Latitudinal clines in peak pupping times have been noted for NE Pacific harbor seals (*P. v. richardsi*) inhabiting regions below approximately 48°N, and for NW Atlantic harbor seals (*P. v. concolor*). No such clines have been observed for those inhabiting the NE Atlantic (*P. v. vitulina*), or regions above approximately 48°N on the outer coast of western North America (Temte *et al.* 1991). Harbor seals inhabiting the inland coastal waters of Puget Sound, Washington State (47°–48°N) and the Vancouver Island region of southern British Columbia (B.C.; 48.5°–51°N) are characterized by late and extended pupping seasons (July–August in B.C., and August–September in Puget Sound) (Temte *et al.* 1991).

While differences in the timing of pupping and breeding has been reasonably well documented for several harbor seal populations, details on birth mass, growth rates, and weaning age and mass have proven more difficult to accurately collect. Birth mass estimates for inshore harbor seal populations have been generally based upon extrapolations from the relationship between fetal mass and fetal ages, or between body mass and pup age (Bigg 1969a, Vaughan 1978, Markussen *et al.* 1989). Other estimates of birth mass have not specified pup ages (Newby 1973, Drescher 1979), or have estimated pup birth masses from carcasses during disease episodes (Harkonen and Heide-Jergenson 1990). Reliable birth data on pups can be obtained only when birth is known to have occurred on the day of capture, while pup growth data requires capture-recapture studies of free-ranging individuals.

The offshore population of *P. v. concolor* has been extensively studied on Sable Island, 160 km east of Nova Scotia, Canada (Boulva and McLaren 1979, Boness *et al.* 1992, Bowen *et al.* 1992a). This unique study area has allowed

researchers access to large numbers of harbor seals not habituated to humans, enabling relative ease of approach, capture, and recapture (Ofstedal 1993, Bowen *et al.* 1994). Harbor seal birth mass, growth rates, weaning age and weaning mass are well documented in this area (Boulva 1975, Bowen *et al.* 1992a, Muelbert and Bowen 1993). However, harbor seals typically inhabit inshore coastal areas (Scheffer and Slipp 1944, Fisher 1952, Bigg 1981), where limited data on such characteristics in the developing harbor seal pup are available due to the difficulties involved with the capture and recapture of adequate numbers of known-aged animals.

Birth mass and growth rate data of known-aged pups provides baseline information that is not only relevant from an ecological perspective, but is also important for studies of physiology and toxicology where potentially confounding variables must be minimized or eliminated. The nursing period and early life are characterized by dramatic changes in this precocious phocid, with age- and condition- related changes in hematology, serum chemistry, immune function, and endocrinology having been observed in young harbor seals (Ross *et al.* 1993, 1994; De Swart *et al.* 1995; Simms and Ross 2000). Ongoing interest in the toxic effects of Persistent Organic Pollutants (POPs) on high trophic level marine mammals, including harbor seals, underlines the need to characterize covariates (*e.g.*, age, growth, sex, and condition) that affect physiological health endpoints to minimize confounding effects (Ross 2000).

British Columbia's 17,175 km of coastline provides habitat for over 100,000 harbor seals, with high densities found in the Strait of Georgia between Vancouver Island and mainland British Columbia (Olesiuk *et al.* 1990). Harbor seals in this region are non-migratory (Bigg 1981), with adults typically remaining within a 20-km² home range area greater than 90% of the time (Cottrell 1996). Breeding generally takes place on small rocky islands where access by researchers is limited by shallow intertidal waters and rocky shoals (Bigg 1969a).

The objectives of this study were to determine: (1) the mass, length, axillary girth, and developmental stage at birth (*i.e.*, extent of lanugo) of newborn *P. vitulina richardsi* pups in southern British Columbia, (2) the growth rates of nursing pups, and (3) pup weaning mass and age.

METHODS

Our study was conducted at harbor seal haul-out sites on intertidal shoals and small rocky islands in the waters adjacent to Sidney Island, British Columbia (48°6'N, 123°3'W; see Fig. 1). Data were collected from July to September 1998. Pupping in this area occurs from late June to early August, but peaks in the third week of July (Bigg 1981). Each day during a two-week period (14–28 July), all haul-out sites in a 10 × 15-km area were visited and newborn pups were tagged. Thereafter, these sites were visited three days per week and tagged pups were recaptured until the weaning of the pups in early September. Pups were recaptured only if the interval since previous capture exceeded four days. Captures involved a rapid approach using a 4.3-m alu-



Figure 1. Harbor seal pups captured in a 10 × 15-km study area encompassing shallow intertidal shoals and small islands in region immediately southeast of Vancouver Island, British Columbia (48°6'N, 123°3'W).

minum boat equipped with a 30-hp outboard motor. Captures were made by hand or with the help of a large fish-landing net with 3-cm nylon mesh. One or two persons carried out the captures and wore protective clothing (knee and elbow pads, gloves, helmet, and life vest) to prevent injury on the slippery and rocky substrate at haul-out sites accessed during low tides. Pups were placed in nylon mesh nets during mass determination and were manually restrained for morphometric measurements. A blood sample was taken from the extradural vein using a Vacutainer system and an 18-g 3.2-cm needle (Becton Dickinson, Rutherford, U.S.A.). Blood was collected in heparinized Plasma Separation Tubes (Becton Dickinson) and stored at 4°C in the dark until processing at our laboratory within 4–8 h. Tubes were centrifuged for 20 min at 400 g, and the plasma was visually inspected as outlined below prior to storage for a concurrent developmental study of retinoid (vitamin A) physiology (Simms and Ross 2000).

All pups were sexed, weighed, and body measurements taken, including axillary girth and standard length. Pups were weighed to the nearest 0.1 kg using a hanging dial spring scale (Accu-Weigh, Korea). Axillary girth and standard length (snout to end of tail) were measured using a soft 1-m tape measure as described elsewhere (Mansfield 1967). Other information recorded included general body condition, tooth eruptions, and a visual estimate of the percentage of the pup covered by lanugo. All captured pups were given numbered interdigital "Rotoriese #2" flexible tags (Dalton Supplies Ltd, Henley-on-Thames, United Kingdom) for subsequent identification at recapture. One or two circular, dome-shaped, 2.5-cm diameter, color-coded epoxy disks (mold designed and developed by primary author) were also attached to the pelage (head mounted) using 5-min epoxy, enabling the identification of individuals at a distance.

Pups were identified as newborns by direct observation of birth, presence of birth fluids, placenta, fresh blood, meconium stool, and/or a pink fleshy umbilicus. A moist white umbilicus indicated an age of <2 d. The period of umbilicus degeneration was documented from a number of field observations (results not shown) and further substantiated by observations of harbor seals raised in captivity.² Pups captured with no umbilicus or a white umbilicus (*i.e.*, >24 h since birth) were not included in birth mass estimates. Lanugo-covered pups were separated into two categories: (1) 5%–50% of the body was covered in lanugo, and (2) $\geq 50\%$ of the body was covered in lanugo. Pups with trace amounts of lanugo (*i.e.*, <5%) were classified as non-lanugo for the purposes of this study, in a manner similar to that described elsewhere (Bowen *et al.* 1994).

Weaning was said to have taken place if each of three criteria were met: (1) blood plasma was clear, (2) the mother was absent, and (3) body mass decreased since the previous capture. We adapted a visual index (Muelbert and Bowen 1993) to classify blood plasma opacity, noting the degree of lipemia on a scale of 0–100. Bowen *et al.* (1985) found that cloudy serum caused by the presence of chylomicrons indicated recent suckling (*i.e.*, <4–6 h) in hooded seals (*Cystophora cristata*), while serum was clear in fasted or weaned pups. We defined a mother as absent if she was not observed in the vicinity of a hauled-out pup prior to recapture. Nursing pups gain mass from ingesting milk, while weaned harbor seal pups undergo a fasting period. Mass loss in the pup was therefore taken as evidence that the pup had been weaned. Based on these criteria and our measures of body mass gain during the nursing period *vs.* body mass loss postweaning, we estimated weaning age and weaning mass in pups that were recaptured two or more times. Estimates for body mass loss of pups once weaned were derived from measurements taken during the opportunistic recaptures of orphaned seal pups (results not shown).

Linear mixed-effects models (LME; S-Plus 4.5) were used to examine the effect of age on the mass gain, body length gain, and axillary girth gain for pups captured three or more times ($n = 7$) (Bowen *et al.* 1992b). This method uses maximum-likelihood parameter estimation. Given the nature of the data we assumed an autoregressive (*i.e.*, AR1) variance-covariance matrix for the subject error terms. All models were compared to the mean model: $y = \mu + E$.

Gains in body mass, girth, and length using data from newborn pups that were recaptured at least once ($n = 11$) during the nursing period were used to generate regressions for these changes from birth onwards for a larger group of individuals. These gains were calculated using data from the first (newborn) and last captures only for these pups (*i.e.*, without any intervening data in the case of multiple recaptures), and single data points for each pup were consequently plotted.

Average daily gain in body mass, axillary girth, and standard length during the first two weeks was compared (paired *t*-test) with the second two-week

² Personal communication from Frances Gulland, The Marine Mammal Center, Sausalito, CA 94965, September 2000.

period of lactation to determine whether increases were constant during the nursing period. The average daily mass gain of pups captured three or more times was also compared to animals captured twice to determine if the frequency of recapture and/or blood sampling influenced growth rates. Standard error (SE) is given as a measure of variability about the mean.

RESULTS

Birth Mass, Girth, and Length

A total of 46 harbor seal pups was initially captured and tagged. Eighteen were determined to be >1 d old and were excluded from this study. Twenty-eight were determined to be <1 d old, these having a mean body mass of 11.2 ± 0.31 kg (Table 1). Birth mass of males did not differ significantly from that of females, but lanugo pups (21.4% of pups; four males and two females) were significantly smaller than non-lanugo pups (78.6% of pups; 11 males and 11 females). Newborn axillary girth and length averaged 54 ± 1.6 cm, and 78 ± 1.9 cm, respectively.

Growth Rates

Seven pups were captured three or more times with the first recapture at 10 d. Pups gained 394 ± 26 g/d (Fig. 2) and axillary girth increased by 6.4 ± 0.59 mm/d (results for this group not shown) during the nursing period. Both mass gain and axillary girth gain were tightly correlated with age ($n = 7$ pups, 23 captures), with LME model regression coefficients of 0.993 ($P < 0.001$) and 0.978 ($P < 0.001$). Increases in body length over time (3.3 ± 0.27 mm/d) were more variable, with a LME model regression coefficient of 0.874 ($P < 0.001$; results for this group not shown). Mass gain during nursing did not differ significantly between males ($n = 4$) and females ($n = 3$), but the small sample sizes provided low statistical power. Daily rate of mass gain did not differ for seals that were recaptured once versus seals that were recaptured more than once.

Body mass, girth, and length data from newborn pups that were recaptured at least once ($n = 11$) during the nursing period are plotted using linear regressions for body mass gain and length gain, and a Gompertz fit for body length gain (Fig. 3).

Weaning Mass and Age

Pups were weaned at an average of 32 ± 1.5 d (range 26–40 d, $n = 7$) and 23.6 ± 1.2 kg (range 20.2–28.6 kg, $n = 7$).

DISCUSSION

Harbor seals are widely distributed along the temperate coastal regions of Europe, North America, and Asia. The adaptation of this pinniped species to

Table 1. Mean \pm SE birth mass, length, and axillary girth of newborn harbor seals live-captured in southern British Columbia (range in parentheses).

	All newborn pups			All newborn pups (both sexes)			Difference lanugo vs. non-lanugo
	All pups (<i>n</i> = 28)	Males (<i>n</i> = 15)	Females (<i>n</i> = 13)	Non-lanugo (<i>n</i> = 22)	Lanugo (<i>n</i> = 6)		
Body mass (kg)	11.2 \pm 0.31 (8.0–14.0)	11.3 \pm 0.43 (8.0–14.0)	11.1 \pm 0.43 (8.6–13.9)	11.6 \pm 0.33 (8.6–14.0)	9.8 \pm 0.44* (9.4–11.0)	* <i>P</i> = 0.015	
Length (cm)	79.1 \pm 0.80 (72–86.5)	78.9 \pm 1.14 (72–85)	79.4 \pm 1.08 (72.5–86.5)	80.3 \pm 0.81 (72.5–86.5)	74.9 \pm 1.27** (72.0–80.0)	** <i>P</i> = 0.004	
Axillary girth (cm)	54.1 \pm 0.83 (44.0–62.0)	54.4 \pm 1.23 (44.0–62.0)	53.8 \pm 1.04 (46.5–60.0)	55.0 \pm 0.81 (46.5–62.0)	50.9 \pm 2.09* (44.0–56.0)	* <i>P</i> = 0.040	

Data grouped by column as: (1) all newborns, including those with trace, moderate, or extensive lanugo; (2) all males, including those with lanugo; (3) all females, including those with lanugo; (4) non-lanugo pups of both sexes, with $\leq 5\%$ lanugo; and (5) lanugo pups of both sexes, with moderate to extensive lanugo ($> 5\%$ body coverage). Significant differences indicated following *t*-tests.

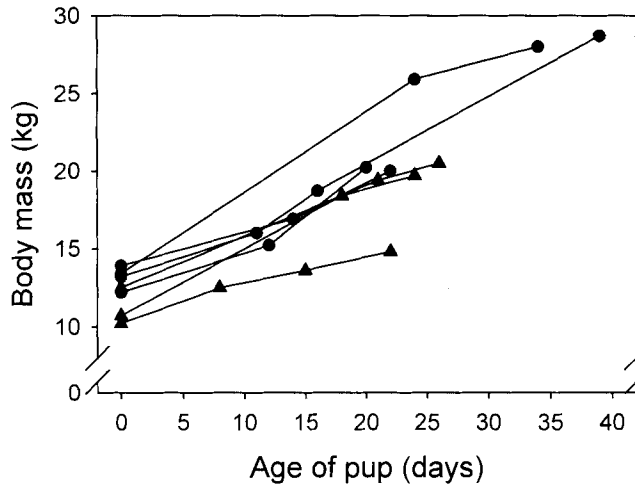


Figure 2. Body mass in individual harbor seal pups ($n = 7$) that were captured at birth (*i.e.*, <24 h old) and subsequently recaptured at least two times at different points during the nursing period. Males represented as circles; females as triangles.

a wide variety of habitats is reflected in subtle variation in morphology, biology, and behavior both within and between the five identified subspecies. For example, the timing of harbor seal pupping may vary between regions so as to coincide with peaks in the abundance of prey which may be important to the survival of weaned seal pups (Temte *et al.* 1991, Temte 1994).

Given the wide ranges observed in peak pupping times and the length of the pupping period for harbor seals inhabiting different areas, variation in the morphological characteristics of newborn harbor seals during their nursing period is also of interest. Much of the detailed information on birth mass and growth rates in pups, as well as maternal energy expenditures, is limited to studies of the Western Atlantic harbor seals (*P. v. concolor*) (Bowen *et al.* 1992a, Bowen *et al.* 1994, Ellis *et al.* 2000). Studies of live-captured mother-pup pairs on Sable Island, Nova Scotia, found that pup birth mass was positively correlated with maternal age in the case of young (*i.e.*, small and inexperienced) mothers, and size (*i.e.*, condition) in intermediate and older mothers (Ellis *et al.* 2000, Bowen *et al.* 2001). Due to the challenges in capturing and recapturing identifiable *P. vitulina richardsi* mother-pup pairs in the rocky intertidal haul-out sites in our study area, we were unable to document maternal influences on pup birth characteristics and development. However, our study does provide an assessment of pup development for this subspecies based on a relatively large sample size of newborns captured during an approximately 3-wk span of the pupping period in southern British Columbia.

We found that the body mass of newborn males did not differ significantly from females, consistent with previous studies on this subspecies (Bigg 1969b, Newby 1973). Others have noted slight differences in male-female birth mass in other subspecies (Boulva 1975, Bowen *et al.* 1994), suggesting that a larger

sample size may help to elucidate sex-based differences in the birth mass of *P. v. richardsi*. Long-term studies of individuals combined with better information on harbor seal mating strategies are needed to understand why young harbor seals may be slightly sexually dimorphic.

The proportion of lanugo-covered newborn pups in our study (21.4%) was comparable to those observed on Sable Island (12.4–26.4%) (Boulva 1975, Bowen *et al.* 1994). Lanugo pups were smaller at birth than non-lanugo pups in both our study and in studies carried out on Sable Island, this being largely attributed in the latter study to smaller (younger) mothers (Bowen *et al.* 1994, Ellis *et al.* 2000).

The average birth mass (11.2 kg) of harbor seals in our study differed slightly from previous estimates for NE Pacific harbor seals (Scheffer and Slipp 1944, Bigg 1969*b*, Newby 1973), but this likely reflects differences in study design, as confirmation of newborn status in these studies was not possible or sample size was small. Published newborn body mass data from NE Atlantic harbor seals were lower than those observed in our study, but this likely reflects measurements taken from non-normal individuals (*i.e.*, victims of the 1988 phocine distemper virus (PDV) epizootic) (Harkonen and Heide-Jergenson 1990). However, mean birth mass of pups in our study was virtually identical to that observed in Sable Island harbor seals, where newborn status was also confirmed during live captures (Boulva and McLaren 1979, Muelbert and Bowen 1993, Bowen *et al.* 1994).

Mass gain and axillary girth gain of individuals were strongly linear during the nursing period, while length gain appeared to be somewhat more variable. Accurate field measurements can be difficult to obtain due to movements of the captured seals and their frequent cranial protraction during handling. Nonetheless, the observed relationships (*i.e.*, linear for length and girth gain, and Gompertz for length gain) suggest that skeletal growth slows later in the nursing period, while the deposition of blubber continues unabated until weaning. More detailed information on growth rates during the first few days of life, or mass loss after weaning, could not be generated in this study, since recapture intervals were generally greater than five days. In addition, the limited sample sizes rendered it impossible to fully examine potential differences in growth or weaning characteristics between male and female pups, or between lanugo and non-lanugo pups.

The nursing period length estimated in our study (mean of 32 d) was within previous estimates of 24–42 d for *P. v. richardsi* (Bishop 1967, Bigg 1969*a*, Newby 1973), although our study represents the first direct estimate of weaning age in free-ranging harbor seal pups of this subspecies. Mean estimated weaning mass (23.6 kg) in our study was similar to the weaning mass (24.9 kg) observed in Sable Island harbor seals (Boulva and McLaren 1979, Muelbert and Bowen 1993, Bowen *et al.* 1994). However, the mean daily growth rate (394 g/d) of pups in our study was approximately half that of Sable Island seals (600–800 g/d) (Bowen *et al.* 1992*a*, Bowen *et al.* 2001). Despite the lower growth rates observed in our study, pups were weaned at a similar mass to those on Sable Island because of the significantly longer lactation period.

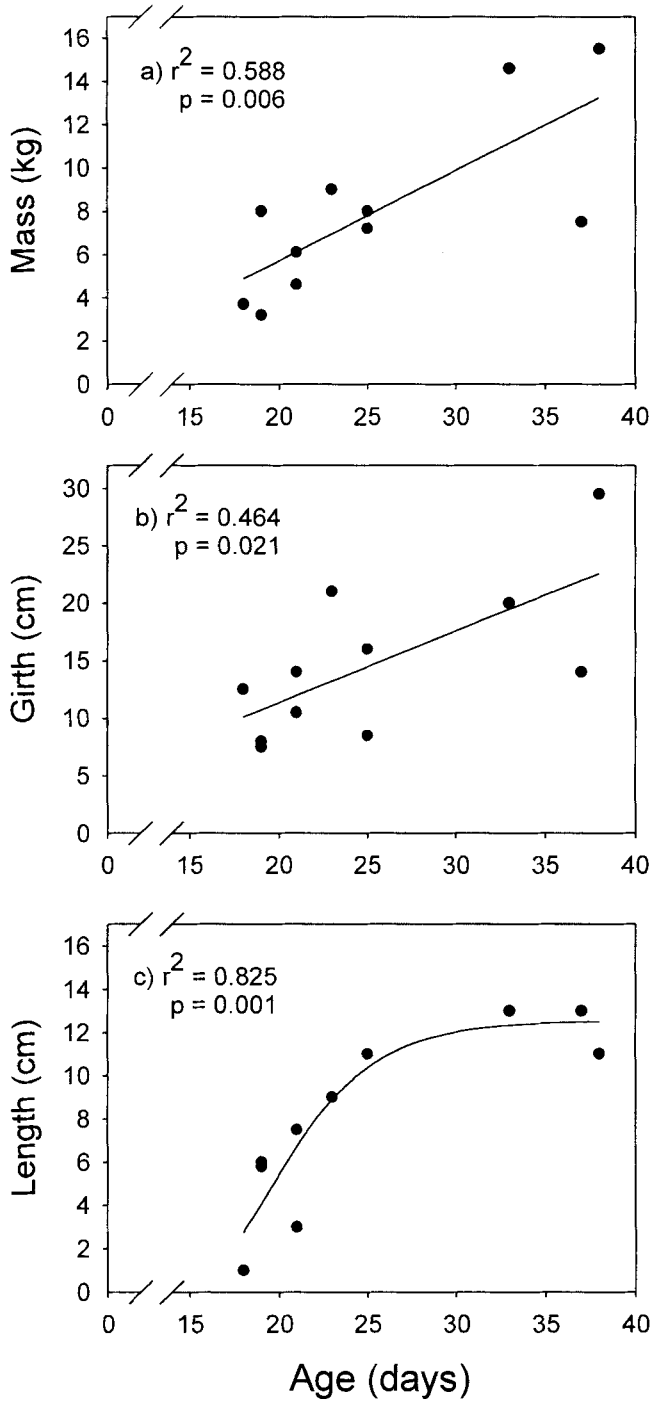


Figure 3. Regressions for gain in (a) body mass (based on a linear fit: $\text{mass} = 0.418x - 2.657$); (b) axillary girth (based on a linear fit: $\text{girth} = 0.624x - 1.143$);

The manner in which genetic and environmental factors each contribute to these similarities and differences between the two subspecies is not clear. Sable Island (43.5°N) is an isolated, offshore, and exposed environment where seals give birth on, or adjacent to, sandy beaches. While a limited number of the haul-out areas used by harbor seals in southern British Columbia are sandy, most are characterized by shallow, rocky intertidal shoals and small islands in a highly productive coastal area, where pups are forced to swim regularly as tides rise. Local prey which may be important to weaned pups consist of diverse fish and invertebrate species. Disturbance of hauled-out mother-pup pairs by a large number of boaters and occasional presence of terrestrial animals in our study area may also have increased the amount of time that mothers and their pups spend in the water. The greater time spent swimming and consequent utilization of energy reserves may therefore be one explanation for the lower growth rates observed in *P. v. richardsi* pups. Further studies on the morphological characteristics of young harbor seals within and between subspecies are needed to better understand the factors underlying the timing and nature of the harbor seal pupping season.

This study represents the first attempt to carry out a comprehensive capture-recapture study of free-ranging NE Pacific harbor seal pups. Understanding the growth rates of free-ranging harbor seal pups represents an important foundation for other developmental studies in this precocious pinniped (Ross *et al.* 1994, Simms and Ross 2000). Interest in the use of this widely distributed species as a sentinel of food chain contamination by persistent environmental contaminants (Ross 2000, O'Shea *et al.* 2000) underscores the importance of collecting further biological data from free-ranging populations. Given the challenges inherent in longitudinal studies in most of its range, further research into the developmental ecology of the harbor seal will require a variety of creative capture techniques (*e.g.*, Jeffries *et al.* 1993) and study designs which can be applied to different habitats and substrate types.

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and (c) body length (based on a Gompertz fit: $\text{length} = 12.55e^{(-3.378e(-19.41 \times \text{age}))}$) of nursing harbor seal pups between birth and their final capture ($n = 11$ pups). Data based on animals recaptured at least once. Regression coefficients (r^2) and levels of significance indicated for each plot.

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