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Identification of skate nursery habitat in the eastern Bering Sea

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ABSTRACT: Identification of habitat used for skate egg deposition has been rarely studied or reported worldwide. Four nursery sites for the Alaska skate *Bathyraja parmifera*, 2 for the Aleutian skate *B. aleutica* and 2 for the Bering skate *B. interrupta* were identified along the upper continental slope in the eastern Bering Sea. All sites were located near undersea canyons from 145 to 380 m depth in relatively flat sandy to muddy bottom habitat. Bottom temperatures were relatively constant throughout the year, varying from 3.7 to 4.6°C. Egg case densities varied between nursery sites and were encountered at the Alaska skate nursery in Bering Canyon at densities greater than 800 000 eggs km^{-2}. Based on egg case composition, sites were predominantly used by a single skate species for egg deposition; however, up to 6 skate species used the habitat commonly. Seasonal sampling indicated that sites were continuously occupied throughout the year, and embryo length composition showed multiple cohorts developing simultaneously. Data from bottom trawl surveys suggest juvenile skates occupy habitats different than nursery sites. The movement of juvenile skates out of nursery habitat after hatching may lessen predation by common predators such as the Pacific cod *Gadus macrocephalus* and the Pacific halibut *Hippoglossus stenolepis.*

KEY WORDS: Elasmobranch · Skate · Reproduction · Egg case · Undersea canyon · Nursery · Alaska

INTRODUCTION

Characterization of habitat used for reproduction and early life stages of oviparous elasmobranchs (i.e. skates, family Rajidae) is virtually unknown, with few studies reported (Hoff 2007, 2008, Love et al. 2008). Identification of nursery habitat for egg deposition may be limited by small size making them difficult to locate, by association with high relief areas (i.e. rocky) that are difficult to sample or by occurrence in deeper waters of the continental slope that are often undersampled (Hitz 1964, Hoff 2007, 2008, Love et al. 2008).

Nursery sites for viviparous elasmobranchs (sharks) are known (Castro 1993, Carlson 1999, Feldheim et al. 2002, Yokota & Lessa 2006) and habitat requirements have been identified for many species. Shark nursery sites may be ephemeral and/or seasonal, and neonates can reside for extended periods using the sites for protection and as an optimal food resource. In contrast, recent findings suggest skate nursery sites remain in use throughout the year, and newly emergent skates exit sites soon after hatching, occupying areas at depths different than those of egg deposition (Hoff 2007, 2008, Love et al. 2008). There appear to be fundamental differences in the nursery habitat use between oviparous and viviparous elasmobranch species, suggesting that habitat identification may be critical for successful management and conservation of these little known fishes (Packer et al. 2003).

In the eastern Bering Sea (EBS) 12 skate species are recognized, with only 3 species comprising the bulk of the skate biomass and populations (Hoff & Britt 2003, 2005, 2009, Lauth & Acuna 2009). The Alaska skate *Bathyraja parmifera* dominates the continental shelf environment (20 to 200 m) and the Aleutian skate *B. aleutica* and the Bering skate *B. interrupta* are the dominant skate species along the EBS slope (200 to 1200 m) (Hoff & Britt 2005, 2009, Stevenson et al. 2008,

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Lauth & Acuna 2009). Combined these 3 species constitute >95% of the skate population and biomass in the entire EBS (20 to 1200 m depth) and are the major components of skate bycatch in non-target commercial bottom trawl and longline fisheries (Stevenson 2004). Other important slope-dwelling species in the EBS include the whiteblotched skate *B. maculata*, the mud skate *B. taranetzi*, the Commander skate *B. lindbergi* and the whitebrow skate *B. minispinosa* (Hoff & Britt 2009).

This study focuses on identification of skate nursery habitat for 3 abundant skate species in the eastern Bering Sea. Four nursery sites for the Alaska skate, 2 nursery sites for the Aleutian skate, and 2 nursery sites for the Bering skate (Fig. 1) are described. Some important biological aspects examined were skate and skate egg case composition, egg case densities and predation on juvenile skates. Nursery habitat parameters include location, temporal use, depth, temperature, bottom topography and associated sessile fauna

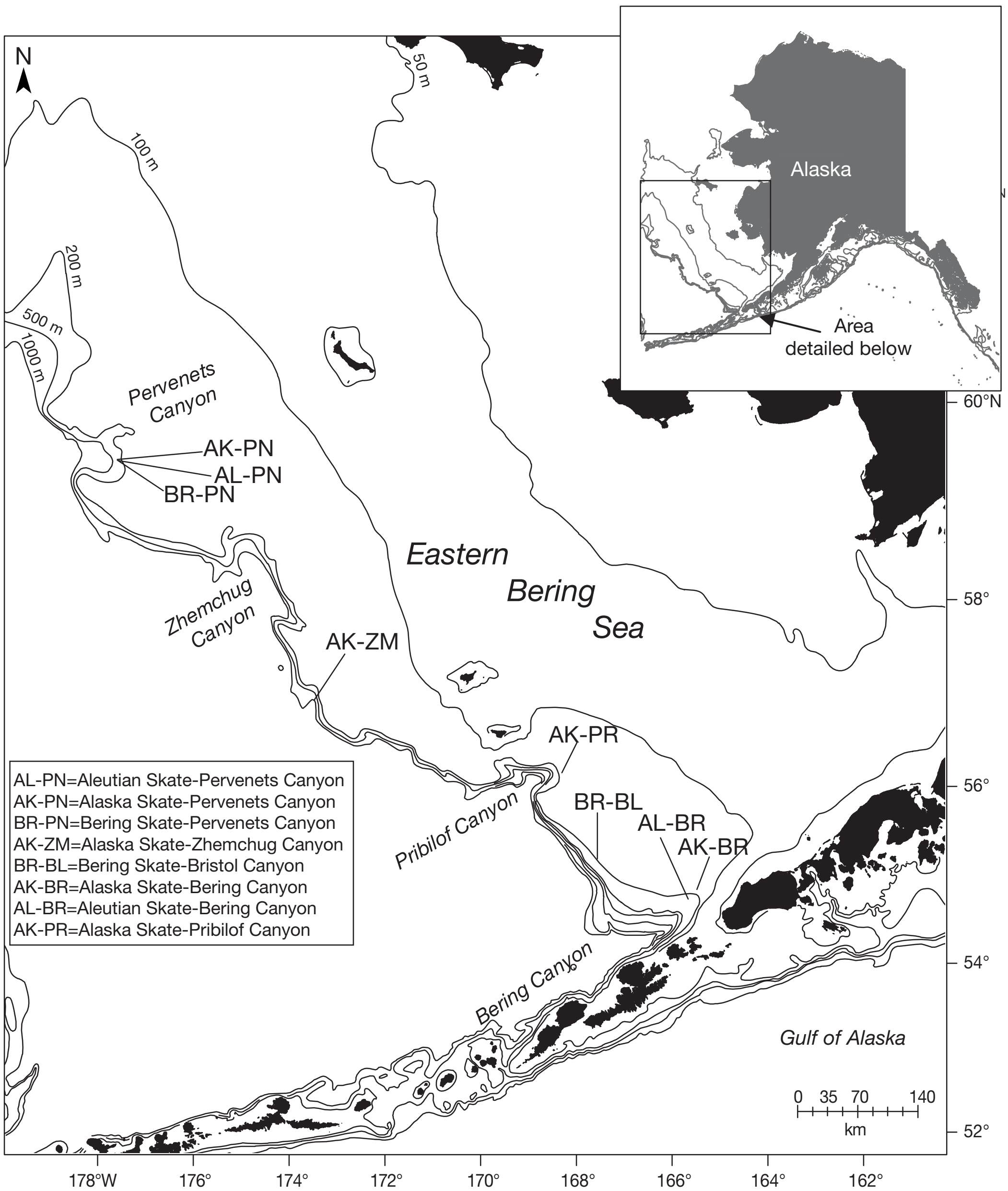


Fig. 1. Location of 8 skate nursery sites in the eastern Bering Sea and their species–canyon location designations. The AK-PR site has not been studied in detailed and is included to document its location in Pribilof Canyon. Inset shows general location of the study area in the Bering Sea

that may assist in identification of habitat used for reproduction.

MATERIALS AND METHODS

Nursery habitat identification. Initial locations of nursery sites were identified based on fisheries data, and previous survey trawls in which large numbers of skate egg cases were reported in the catch. Identified sites were subsequently sampled using bottom trawls in an adaptive sampling approach to identify the egg case distribution and estimate the size of the habitat used for egg deposition. At each site trawls were conducted in each of 4 directions (north, south, east, west) at approximately 0.5 to 1.0 km start distance from the previous trawl. Trawling proceeded in a single direction until total egg case counts within a haul consistently lessened. During trawling it was found that due to the 'stickiness' of egg cases in the trawl webbing it could not be determined whether eggs encountered were new or from a previous trawl; therefore, a reduced egg case density of <1000 eggs km^{-2} (ca. 10 to 15 eggs trawl^{-1}) was used as a stopping criteria and indicated the end of the egg case distribution or a reduction to non-detectable limits by the trawl. In sites where seasonal sampling occurred, additional trawls were conducted in the high density areas. Each site was sampled a varying number of times and seasons between 2004 and 2008 and data presented are from all sampling periods (Table 1). The ship's echosounder (Es60) input was used to identify any unique relief, sediment type and hardness during trawling operations.

Bottom trawl sampling methods. Trawl samples conducted at skate nursery sites and those of Alaska Fisheries Science Center (AFSC) survey trawls on the EBS shelf (0 to 200 m depth) used similar trawling methods (for details see Stauffer 2004, Lauth & Acuna 2009). The trawl used was an 83-112 eastern otter trawl with a 25.3 m headrope and 34.1 m footrope that consisted of a single firehose-wrapped chain lacking any bobbins or discs, and 32 mm stretched-mesh liner in the cod end. At egg deposition sites, towing time was shortened from a standard 30 min trawl to between 5 and 10 min due to the large biomass and uncertainty of location with long tow distances. During each tow, starting and ending latitude, longitude and bottom depth were recorded; net width was recorded using acoustic trawl mensuration gear, and bottom temperatures were recorded using a Seabird micro-bathythermograph data recorder attached to the net. The swept area was estimated from average net width and distance fished during each trawl. Data for skate and egg depth and temperature distribution were collected from the annual EBS shelf survey (8 to 200 m) and the biennial EBS slope survey (200 to 1200 m) using AFSC standardized methods (for details see Stauffer 2004, Hoff & Britt 2009, Lauth & Acuna 2009). The slope trawl used was a Poly Nor'eastern net with a 27.2 m headrope and 24.9 m footrope consisting of mudsweep roller gear and 32 mm stretched-mesh line in the cod end.

Biological data at nursery sites. Fishes, invertebrates and skate egg cases were identified, weighed and enumerated during each sampling period. Egg cases were further sorted and counted into those possessing a developing embryo (full) or those which were post-hatch or otherwise void of an embryo or contents (empty). Density estimates (catch per unit effort [CPUE] = no. skates km^{-2} or no. egg cases km^{-2}) were calculated as the number of individuals in each trawl divided by the trawl area swept. The percentage of full eggs was calculated as the number of full eggs divided by the total egg counts by species in each haul. Stomach contents from selected predatory species and skates were examined during all sampling periods at nursery sites. Fish weights were recorded to the nearest 0.1 g and lengths to the near-

Table 1. Skate nesting sites of the eastern Bering Sea; their egg density characteristics and bottom temperature. Temperatures in **bold** text represent the month and bottom temperature where maximum egg case densities and percent developing eggs were sampled

Nursery site designation	Depth of maximum egg case density (m)	Bottom temperature (°C)									Maximum egg density (no. eggs km^{-2})	Eggs with embryos (%)
		Jan	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov		
Alaska skate–Pervenets Canyon (AK-PN)	316						**3.9**				334 163	62.6
Alaska skate–Zhemchug Canyon (AK-ZM)	217					**3.9**					610 064	80.2
Alaska skate–Pribilof Canyon (AK-PR)	205			**3.8**	3.8		4.0				16 473	
Alaska skate–Bering Canyon (AK-BR)	145	4.3	4.1		4.2	**4.5**	4.5		4.4	4.6	800 406	40.9
Aleutian skate–Pervenets Canyon (AL-PN)	320						3.9		**3.8**		81 927	68.0
Aleutian skate–Bering Canyon (AL-BR)	380	**4.3**	4.0			3.9	4.0	3.8	3.7	4.0	62 992	86.7
Bering skate–Pervenets Canyon (BR-PN)	337						**3.9**		3.8		49 567	33.0
Bering skate–Bristol Canyon (BR-BL)	156					**4.2**					6 188	56.0

est 1.0 cm. Stomach contents were sorted into prey categories and identified to the lowest possible taxa, enumerated and weighed. The presence and abundance of juvenile skates in the stomach was recorded. A random sample of full skate egg cases chosen for embryo measurements was preserved in either 10% formalin or 95% ethanol from each egg deposition site. Embryos were removed from egg cases and total lengths (TL including tail filaments, mm) were measured. Eggs containing embryos of approximately <15 mm were considered in stage 1 and not routinely measured due to the difficulty of identification and measurement of the embryo.

Historical skate and egg case data from AFSC surveys. The depth distribution at size (length) for the 7 most abundant skate species was obtained from the AFSC's EBS shelf and slope groundfish surveys conducted simultaneously in 2000, 2002, 2004 and 2008 for the slope species, and from 2000 to 2008 for the Alaska skate. Data for each species irrespective of sex was pooled for all survey years and an estimated mean depth (m) and SE of the depth estimated for each length unit (cm TL).

Encounters of skate eggs from survey trawls conducted in the EBS was obtained from the AFSC's groundfish trawl database using all EBS bottom trawl survey data from 1982 to 2009 for depths 8 to 1200 m. Data were pooled for all survey years and a density estimate (mean CPUE = no. eggs km^{-2}) was calculated as the total number of skate eggs encountered at a 25 m depth interval divided by the total area swept by all survey trawls completed in that depth interval. An alternative density estimate (mean CPUE = no. of eggs km^{-2}) was estimated for bottom temperature as the total number of skates eggs encountered at each 0.1°C bottom temperature interval divided by the total area swept by all survey trawls conducted at that temperature.

RESULTS

Nursery habitat

Each site was given a designation based on the predominant species of skate egg cases present and the marine canyon associated with the site (Fig. 1). Designations were: Alaska skate–Pervenets Canyon (AK-PN), Alaska skate–Zhemchug Canyon (AK-ZM), Alaska skate–Pribilof Canyon (AK-PR), Alaska skate–Bering Canyon (AK-BR), Aleutian skate–Pervenets Canyon (AL-PN), Aleutian skate–Bering Canyon (AL-BR), Bering skate–Pervenets Canyon (BR-PN), and Bering skate–Bristol Canyon (BR-BL).

The AK-BR site was sampled most frequently with a total of 29 trawls and sampling completed in nearly all months of the year. The AK-PN site was the least frequently sampled known from only a single trawl conducted during August of 2006. The AK-PR site has not been mapped and is known from a past AFSC survey trawl (1979), which encountered an egg density of >16 000 eggs km^{-2}. There are numerous reports in National Marine Fisheries Service (NMFS) fishery data for this location, and a 2008 AFSC survey trawl conducted near the site encountered many empty skate egg cases, which suggests a possible large nursery site in the vicinity (Hoff & Britt 2009).

In general skate nursery sites possessed areas of high numbers of viable eggs (>30%) surrounded by broadly scattered areas of predominantly (>70%) empty egg cases (Fig. 2). Egg cases were encountered lying directly on the seafloor on flat sandy to muddy bottom and were found over a narrow depth range of the upper slope and outer shelf from 145 to 380 m. Sites were commonly associated with canyon heads with 3 in Pervenets Canyon, 1 south of Zhemchug Canyon, 1 in Pribilof Canyon, 2 associated with Bering Canyon, and 1 in Bristol Canyon. Depths varied little within individual sites with the highest concentrations of eggs often occurring over <20 m depth range. Composition of sessile attached invertebrates provided little evidence of substrates or distinct species associations that could be used to identify site habitat. Sponges (0.4 to 1457.03 kg km^{-2}), sea whips (0.4 to 294.10 kg km^{-2}) and polychaete worm tubes (0.16 to 165.43 kg km^{-2}) were among the 3 most common sessile invertebrates encountered and all were in relatively low densities. Bottom temperatures for all sites and sampling times ranged from 3.7 to 4.6°C (Table 1). The most complete seasonal sampling conducted at the AK-BR site showed bottom temperatures varied by only 0.5°C throughout the year.

Biological data at nursery sites

Maximum egg case densities varied dramatically between sites and among the 3 species (Table 1). Alaska skate nursery sites had the highest egg case densities with the highest at the AK-BR site, while the Aleutian skate and Bering skate nursery sites had 1 and, at the BR-BL site, even 2 orders of magnitude lower egg densities. Both the Aleutian and Bering skate sites displayed trends opposite those of the Alaska skate site by having higher egg case densities at northern sites than at southern sites (Fig. 2). Nursery sites possessed up to 86% eggs containing developing embryos (full eggs), and in general egg case densities were higher for the Alaska and Bering skate sites during June to August sampling, and during the October

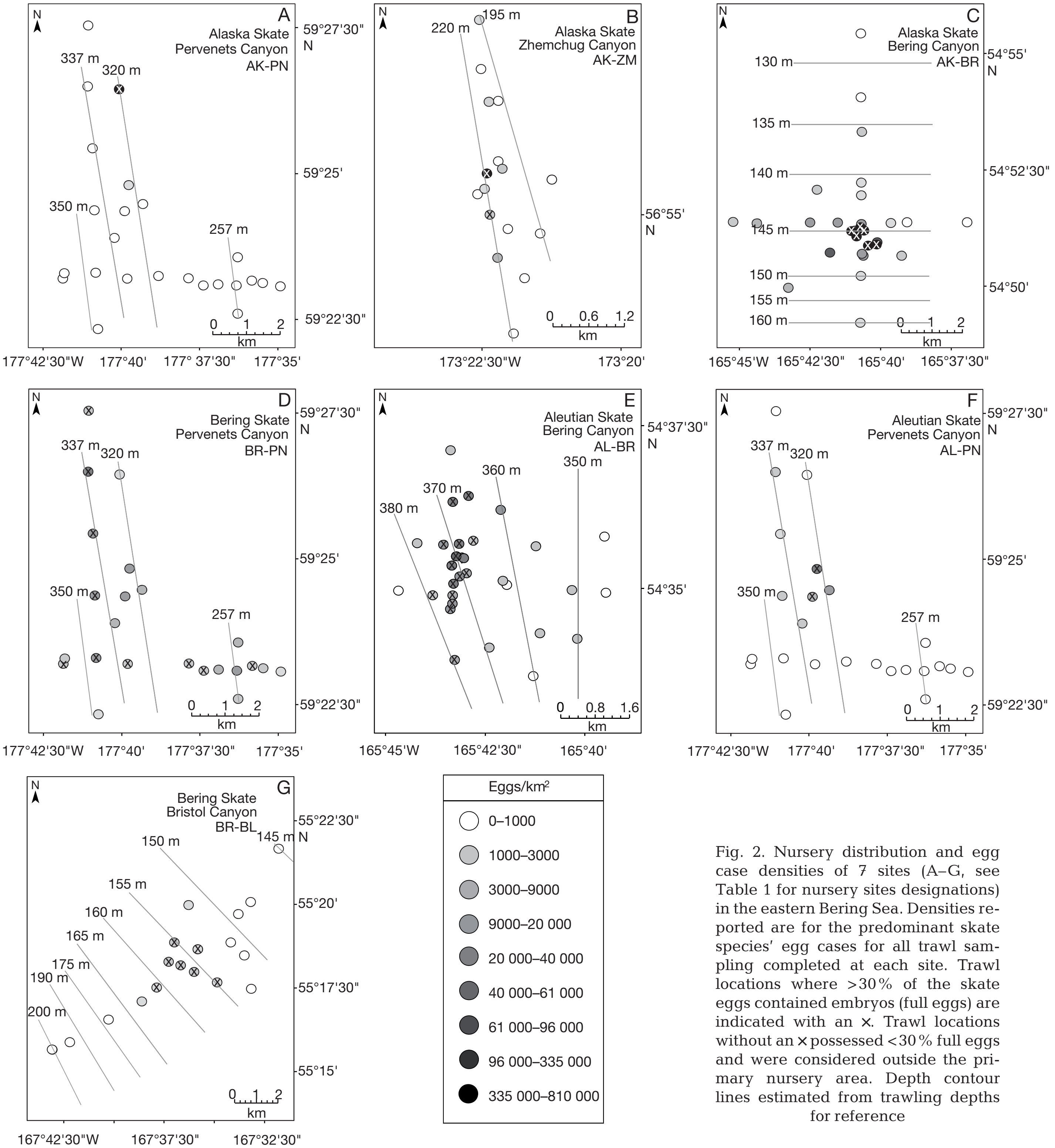


Fig. 2. Nursery distribution and egg case densities of 7 sites (A–G, see Table 1 for nursery sites designations) in the eastern Bering Sea. Densities reported are for the predominant skate species' egg cases for all trawl sampling completed at each site. Trawl locations where >30% of the skate eggs contained embryos (full eggs) are indicated with an ×. Trawl locations without an × possessed <30% full eggs and were considered outside the primary nursery area. Depth contour lines estimated from trawling depths for reference

to January sampling for the Aleutian skate site, although complete seasonal sampling is lacking at all sites throughout the year to evaluate the trends thoroughly.

Species diversity of adult or juvenile skates was often high at nursery sites while species diversity of egg cases was low. Nursery sites had egg cases from 3 to 6 skate species; however, egg case composition reflected a predominance of a single skate species' eggs at each site (Fig. 3). An exception to this was the AL-PN site, where the Bering skate eggs comprised nearly 40% of the egg case composition. In general, the Bering skate appeared to deposit eggs across a much broader area and at lower densites than the Alaska or Aleutian skates. Encounters of post-hatch and adult skates showed the Alaska skate as the dominant species at the Alaska skate sites and the BR-BL site, and less common at other sites. Aleutian skate sites (AL-PN and AL-BR) and the Bering skate site BR-PN were dominated by the immature and adult stages of the mud skate; other skates such as the whiteblotched skate, Aleutian skate, Bering skate and Alaska skate were also in abundance at these sites.

Pacific cod *Gadus macrocephalus*, Pacific halibut *Hippoglossus stenolepis*, Aleutian skate and whiteblotched skate all consumed newly emergent skates at nursery sites (Table 2). In general, the predation level (number of prey per number of fish examined) estimated from sites (29.07%, Table 2) in the present study was several orders of magnitude higher than predation levels estimated for Pacific halibut and Pacific cod collected from widely scattered samples from a seasonal survey conducted throughout the EBS shelf and slope (0.07%, AFSC Feeding Ecology Lab unpubl. data).

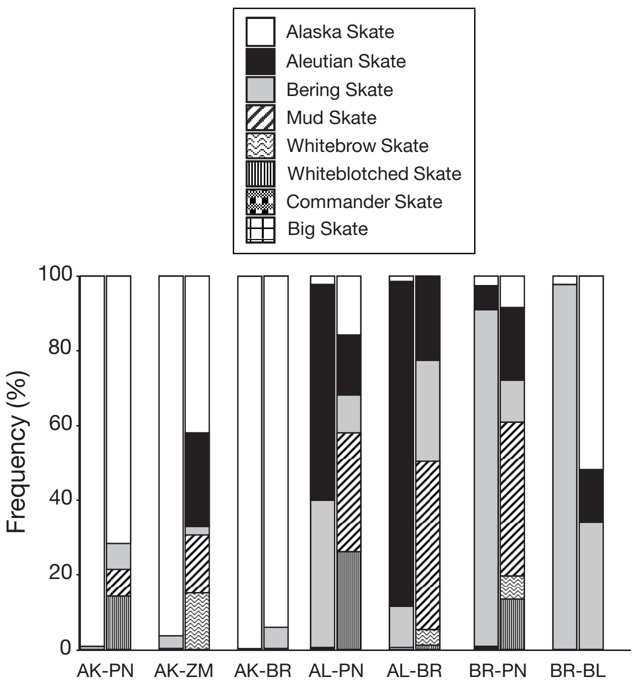


Fig. 3. Species composition of skate egg cases (left bar of each pair) and juvenile and adult skates (right bar of each pair) for each nursery for all trawls combined conducted at that site. Each set of bars represents a comparison between the egg case composition and the post-emergent skates encountered at the individual nursery site. See Table 1 for nursery site designations

Most consumed skate specimens at nursery sites were partially to entirely digested, which limited positive identification; however, based on size, all skates consumed appeared to be neonates of the Alaska or Bering skates.

Embryo length composition from 5 nursery sites showed that developing embryos spanned a wide size range, some with multiple cohorts (Fig. 4). Most sites possessed eggs that were recently deposited (stage 1 = little development) and in early stages of embryo development (<40 mm), and those near hatching size (approximately 250 mm for the Aleutian and Alaska skates, 160 mm for the Bering skate) (for description of embryo stages see Hoff 2008, 2009a).

Historical skate and egg case data

Historical survey data showed consistent patterns of ontogenetic shifts in habitat for the 7 EBS slope skate species examined. The Alaska skate juveniles used the inner and middle shelf with nursery sites and adults primarily found along the outer shelf and slope (Fig. 5A; Hoff 2008). Likewise, the Aleutian and Bering skates nursery sites and adults were found along the outer shelf and slope edge while juvniles used deep slope habitat (Fig. 5B–G). General ontogenetic movement and habitat use of other slope-dwelling skate species, such as the whiteblotched skate, mud skate, Commander skate and whitebrow skate, were all similar to those of the Aleutian and Bering skates (Fig. 5C–G).

Data summarized from 28 yr (from 1982 to 2009, >14 000 trawls) of AFSC survey bottom trawls indicate that skate nursery sites are primarily an outer shelf to upper slope phenomenon. AFSC survey trawls were conducted between 8 and 1200 m depths across the EBS shelf and upper slope region and the distribution of skate egg cases indicated that 92% of all egg cases were encountered between 125 and 400 m depths (Fig. 6). Bottom temperatures from AFSC surveys ranged from –2.1 to 13.7°C with 90% of skate egg cases occurring at bottom temperatures from 3.0 to 5.0°C (Fig. 6).

DISCUSSION

Skate nursery habitats identified in the present study appear closely tied to the outer shelf and upper slope canyon areas, particularly canyon heads, in the EBS. The EBS possesses some of the largest undersea canyons in the world (Carlson & Karl 1988), which stretch across the shelf–slope interface from the international dateline to Unimak Pass. Unique habitats can be formed at the heads of canyons due to currents

Table 2. Predator species examined at each skate nursery site. Frequency of occurrence (number of individual predators with skates as prey items) and the number of skates consumed combined for each site and predator species. Predominant prey is by weight from entire stomach contents. –: no prey, empty stomach

Nursery site designation Species	n	Predator size range (cm)	Frequency of occurrence	Total skates as prey	Predominant prey
Alaska skate–Pervenets Canyon (AK-PN)					
Pacific cod	4	55–74	2	5	Skate, shrimp
Pacific halibut	1	82	0	0	Octopus
Alaska skate–Zhemchug Canyon (AK-ZM)					
Arrowtooth flounder	73	31–71	0	0	Fish, shrimp
Pacific cod	24	56–90	9	35	Pollock, shrimp, crab
Pacific halibut	3	80–141	0	0	Pacific cod, cephalopod
Bigmouth sculpin *Hemitripterus bolini*	5	53–63	0	0	Fish
Bering skate	1	80	0	0	Amphipod
Alaska skate	24	94–107	0	0	Pollock, fish, shrimp, crab
Aleutian skate	16	83–132	1	1	Fish, shrimp
Whitebrow skate	9	71–80	0	0	Shrimp
Mud skate	9	61–71	0	0	Amphipod, shrimp
Alaska skate–Bering Canyon (AK-BR)					
Arrowtooth flounder	140	20–81	0	0	Euphausid shrimp, pollock
Pacific cod	170	35–102	5	10	Crab, pollock
Pacific halibut	63	33–92	9	30	Crab, pollock
Great sculpin *Myoxocephalus polyacanthocephalus*	3	47–63	0	0	Pollock, tanner crab
Greenland turbot	1	83	0	0	–
Bering skate	36	55–82	0	0	Euphasid shrimp
Alaska skate	178	62–115	0	0	Pollock
Aleutian skate–Pervenets Canyon (AL-PN)					
Whiteblotched skate	1	101	0	0	Cephalopod
Mud skate	2	36–47	0	0	Gamarid, polychaete
Greenland turbot	5	66–68	0	0	–
Bigmouth sculpin	1	58	0	0	–
Aleutian skate–Bering Canyon (AL-BR)					
Arrowtooth flounder	150	34–67	0	0	Cephalopods, myctophids
Pacific cod	4	48–65	0	0	Shrimp
Pacific halibut	33	39–82	0	0	Crab, pollock
Sablefish *Anoplopoma fimbria*	9	45–62	0	0	Fish
Bigmouth sculpin	8	43–68	0	0	Pollock
Greenland turbot	67	60–91	0	0	Fish
Bering skate	34	40–79	0	0	Euphausid shrimp, crab
Aleutian skate	24	27–158	0	0	Shrimp, pollock, crab
Whitebrow skate	12	77–82	0	0	Shrimp
Mud skate	123	44–76	0	0	Euphausid shrimp
Bering skate–Pervenets Canyon (BR-PN)					
Pacific cod	6	53–83	1	2	Fish, shrimp, crab
Pacific halibut	9	77–96	0	0	Pollock, cephalopod
Bigmouth sculpin	9	56–69	0	0	Fish
Greenland turbot	16	50–100	0	0	Squid
Bering skate	22	23–80	0	0	Gammarid, shrimp
Alaska skate	16	74–112	0	0	Pollock
Aleutian skate	33	40–140	0	0	Pollock, euphausid
Whitebrow skate	13	62–79	0	0	Shrimp
Mud skate	51	35–69	0	0	Gammarid, polychaete, crab
Whiteblotched skate	22	55–107	1	2	Pollock, shrimp, cephalopod
Bering skate–Bristol Canyon (BR-BL)					
Arrowtooth flounder	85	31–87	0	0	Pollock, cephalopod
Pacific cod	66	38–87	0	0	Pollock, crab
Pacific halibut	6	59–115	0	0	Pollock
Bigmouth sculpin	1	59	0	0	Fish
Greenland turbot	2	89–90	0	0	–
Bering skate	15	40–75	0	0	Crab, fish, shrimp
Alaska skate	19	28–114	0	0	Pollock, amphipod
Aleutian skate	4	86–155	0	0	Pollock, crab

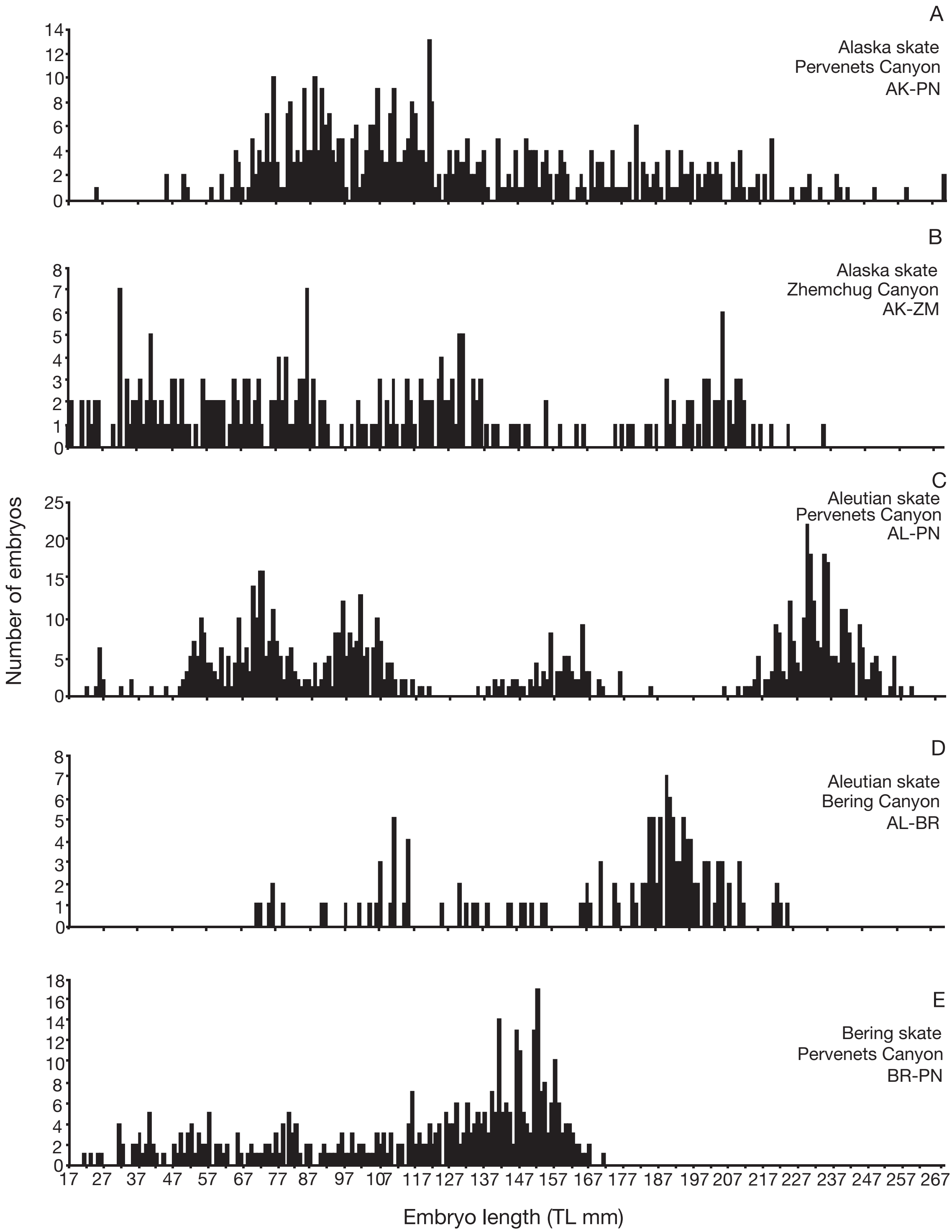
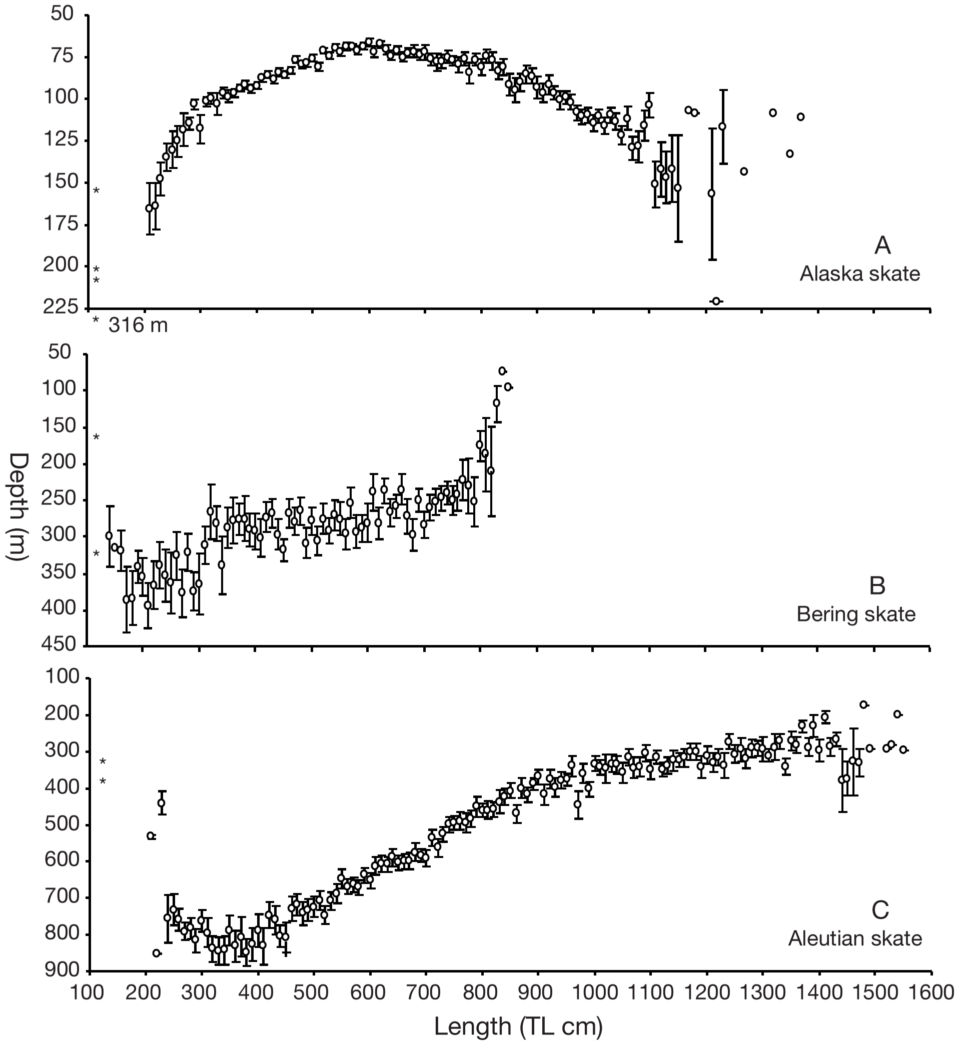


Fig. 4. Length composition by skate species of developing embryos from random samples at each nursery site indicated (see Table 1 for nursery site designations). Stage 1 eggs (not shown) are newly deposited eggs and show little embryo development or possessed embryos that were too small for measurements. The histogram represents the number of embryos developed further enough to be available for measurement. (A) stage 1 n = 134, embryo n = 489; (B) stage 1 n = 97, embryo n = 265; (C) stage 1 n = 101, embryo n = 707; (D) stage 1 n = 3, embryo n = 140; (E) stage 1 n = 119, embryo n = 404. Eggs from nursery sites A, B and E were collected in August and C and D came from October sampling. TL: total length



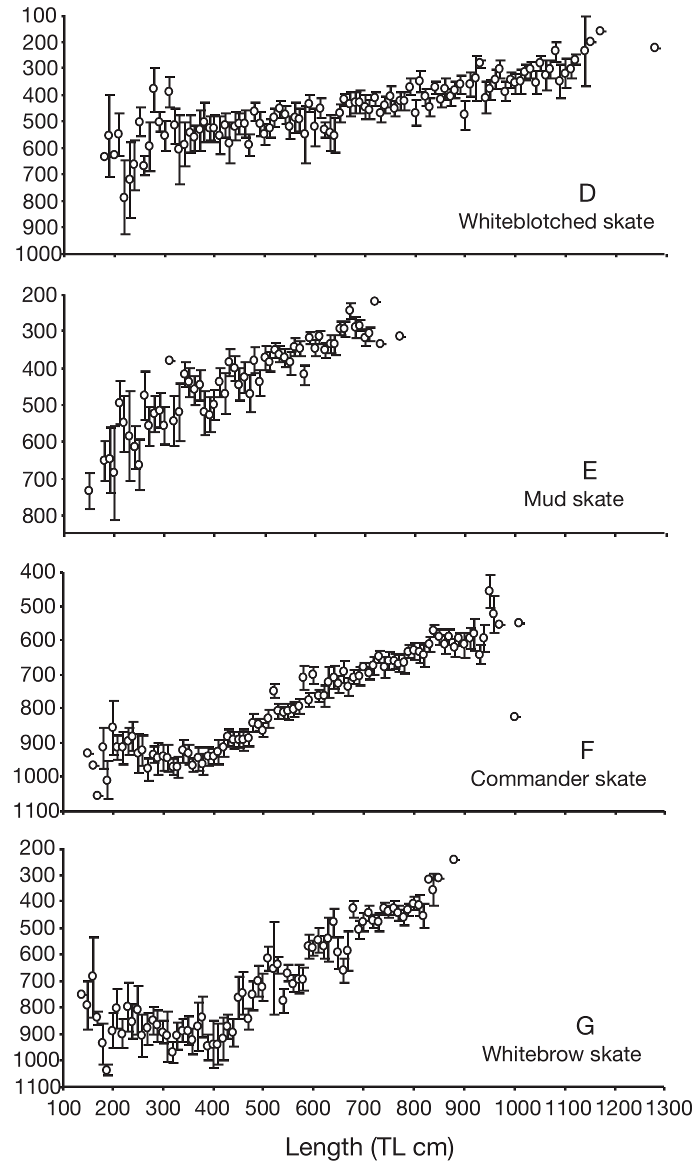


Fig. 5. Mean depth for each centimeter length group for the 7 most abundant skate species in the eastern Bering Sea: (A) Alaska skate n = 9944; (B) Aleutian skate n = 4027; (C) Bering skate n = 2244; (D) whiteblotched skate n = 983; (E) mud skate n = 668; (F) Commander skate n = 1322; (G) whitebrow skate n = 789. Error bars represent the SE for depth at each size category. Data are from the Alaska Fisheries Science Center's standard bottom trawl surveys of the shelf and upper slope during years 2000, 2002, 2004 and 2008. Asterisks (*) indicate the depth of nursery sites known for each species for reference. Note that scaling of *y*-axis differs. TL: total length

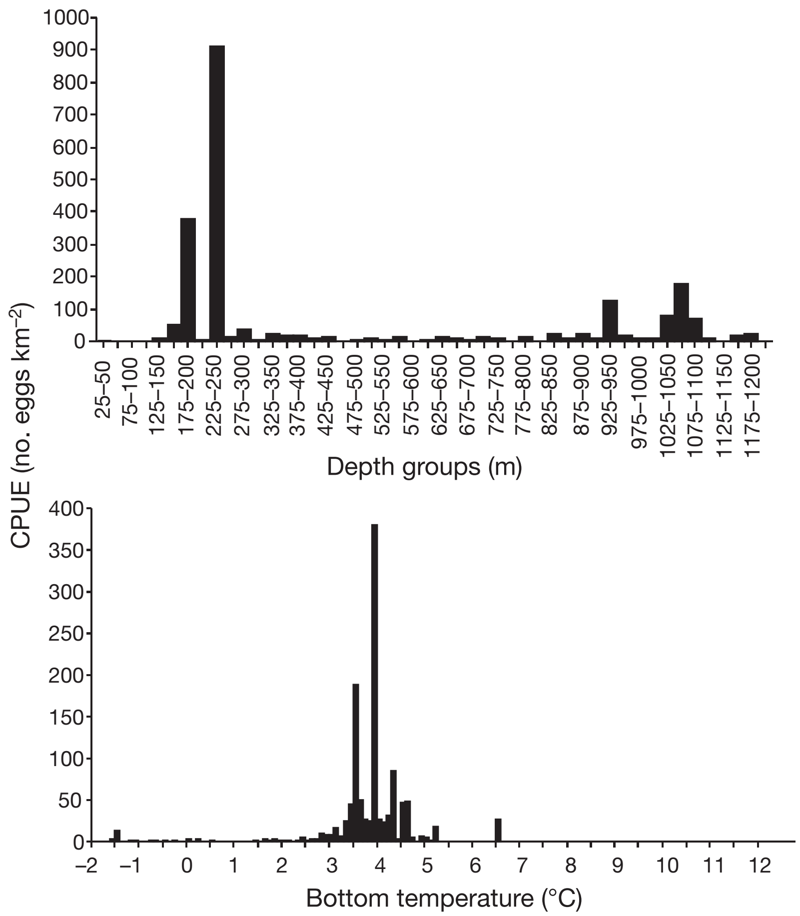


Fig. 6. Mean catch abundance in the eastern Bering Sea of skate egg cases by depth group (25 m interval, top panel) and by bottom temperature (bottom panel) from the Alaska Fisheries Science Center's standard bottom trawl surveys for years 1982 to 2009. CPUE: catch per unit effort

(Stabeno et al. 1999), nutrients (Whitledge & Luchin 1999), sediment types (Karl & Carlson 1987) and temperature regimes (Luchin et al. 1999). These areas possess physical features that may produce optimal conditions for the long development time required by embryos in sub-arctic waters (Hoff 2007, 2008, 2009a). EBS canyons can be highly productive with northerly slope currents causing upwelling and high primary production (Springer & McRoy 1996, Stabeno et al. 1999), which in turn can support high biomass of birds (Piatt et al. 2006), mammals (Loughlin et al. 1999) and fish and invertebrate species (Brodeur 2001, Stevenson et al. 2008). Nursery sites located in highly productive areas can provide ample prey for reproductively active skates. Diets of mature skates at nursery sites suggest feeding occurs during reproductive periods and throughout the year (Hoff 2008). Readily available food during protracted egg laying periods would lessen the need for energy expenditures and forays for food outside nursery habitat. The abundant prey also may explain the high biomass and diversity of skate species and the presence of other large predatory fish species such as Pacific cod, Pacific halibut and arrowtooth flounder *Atheresthes stomias* found at nursery sites.

Skate embryo development time is correlated with water temperature (Berestovskii 1994, Hoff 2007, 2008, unpubl. data) and shorter development times may increase recruitment potential through decreased exposure to predation (Hoff 2007, 2008, 2009b) and greater hatching success. The upper slope environment has relatively warm and stable average annual bottom temperatures when compared with the whole EBS. Seasonal sampling from the Alaska skate and Aleutian skate sites (AK-BR, AL-BR) in the southern EBS show water temperatures varying by only 0.5°C annually (Table 1). Shallower shelf waters in most winters are ice-covered in the central EBS and bottom water temperatures reach <1°C for many months of the year (Niebauer et al. 1999). Survey data indicates skate nursery sites may be concentrated at depths and temperatures similar to those that exist on the outer continental shelf and upper slope of the EBS.

Bottom structure, identified from species composition, gear performance and echosounder data, at nursery sites showed relatively flat sandy bottoms with no vertical structure or hard (rocky) substrates. Nursery sites in rocky reefs and high energy flow areas like that recently reported from Monterey Canyon (Love et al. 2008) and those in the Aleutian Islands (unpubl. data) suggest skate eggs may require attachment to benthic structures such as rocks and sponges to prevent them from being dispersed from optimal habitat. EBS skates may not require attachment structure as the EBS slope currents are slower than those of rocky reef nursery sites in Aleutian Island passes (Reed & Stabeno 1999). Moderate currents such as those along the upper slope of the EBS may create sufficient water flow across the egg surface to sustain metabolic processes (Hoff 2007, 2008, Leonard et al. 1999) and ensure eggs are not covered with sediments, yet moderate enough not to scatter eggs up onto the shelf or into deeper waters to suboptimal habitat.

Skate nursery sites in the EBS show evidence of continous use throughout the year as well as a persistence through time. Fisheries data from bottom trawling in this region indicate North Pacific fisheries observers have reported large catches of skate egg cases from the AK-BR site for >20 yr and other locations for at least 10 yr (North Pacific Fisheries Groundfish Observer Program unpubl. data).

Generalized lifetime movement patterns and nursery site use for EBS skates suggest unique habitat requirements for each life stage of embryo, juvenile, immature and mature skates (Fig. 7). Although the upper slope environment may be optimal as nursery habitat during embryo development, it appears not to be for neonates and juvenile skates. Neonates of slope-dwelling skate species migrated to deeper slope waters and returned to shallower depths with increased size, reaching the upper shelf–slope interface at mature sizes. The Alaska skate is primarily a shelf species and movement patterns showed this species used the depths of the inner and middle shelf of the EBS for immature sizes (Hoff 2007, 2008) and returned to the outer shelf depths at mature sizes (Matta & Gunderson 2007) where the juveniles and nursery sites occurred. The dramatic shift from nursery site depths for neonates and juveniles to deeper or much shallower water may be directly linked to predator avoidance. Juvenile skates that use the lower slope habitat after emergence may avoid predation as the large predatory fish species prevalent at lower slope depths, such as the giant grenadier *Albatrossia pectoralis*, the arrowtooth flounder *Atheresthes stomias* and the Greenland turbot *Reinhardtius hippoglossoides* have not been shown to prey on juvenile skates (AFSC Feeding Ecology Lab unpubl. data). The predators of neonate skates, Pacific cod and Pacific halibut, rarely occur below 600 m along the eastern Bering Sea slope (Hoff & Britt 2009) and are smaller in the middle and inner shelf than in the outer shelf and upper slope (Lauth & Acuna 2009) where nursery sites occur. Predator avoidance by newly emergent neonates may allow for high recruitment potential by separation of predator and prey during early life stages.

Skate nursery site location and surrounding physical oceanographic characteristics, coupled with skate behavior, may be critical elements for successful skate reproduction. Patterns relating to the general distribution and habitat requirements for skates are emerging from this study. The unique physical relationship between skate nursery site placement and canyon habitat remains to be studied in detail. However, highly productive canyon areas are often heavily fished with bottom trawl and longline, which increases the vulnerability of the most critical life stages of skates (reproductive adults and developing embryos) as there is a direct overlap of zones of high fishing effort and skate nursery habitat. Identification and characterization of these fragile habitats are the important first steps in developing management and conservation strategies for these vulnerable species.

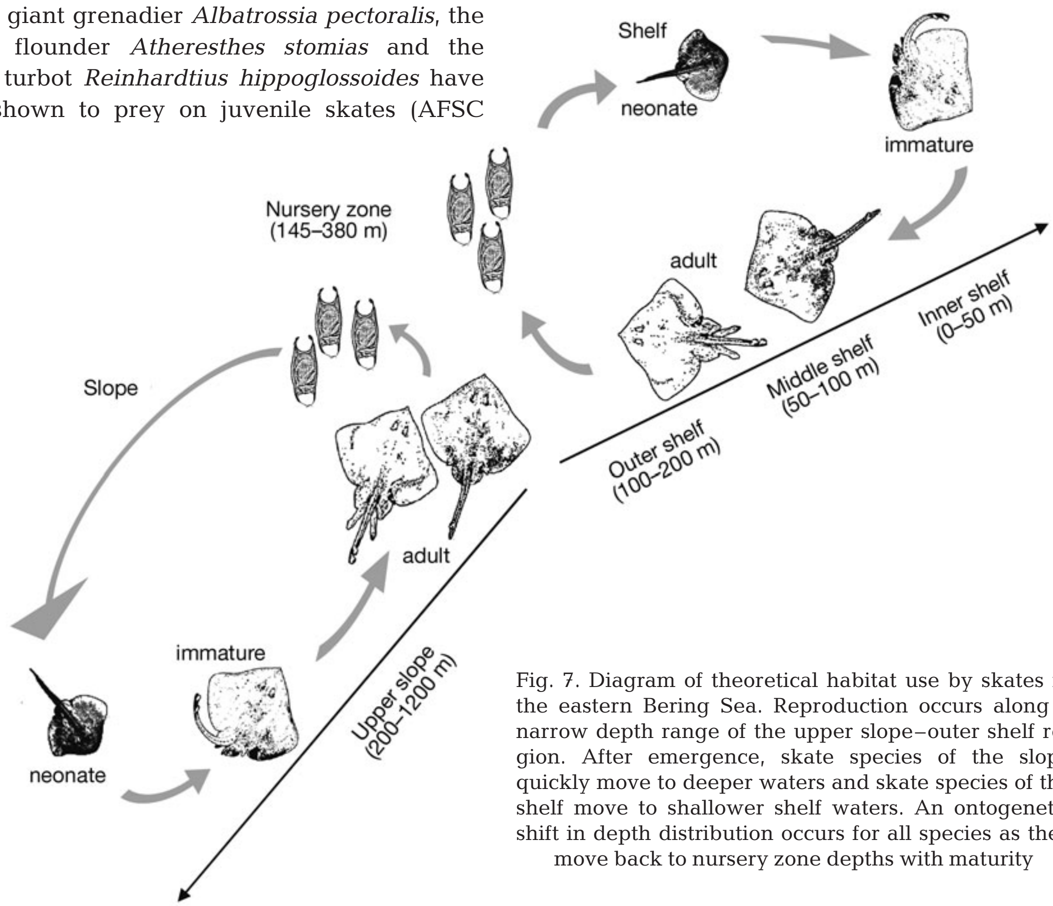


Fig. 7. Diagram of theoretical habitat use by skates in the eastern Bering Sea. Reproduction occurs along a narrow depth range of the upper slope–outer shelf region. After emergence, skate species of the slope quickly move to deeper waters and skate species of the shelf move to shallower shelf waters. An ontogenetic shift in depth distribution occurs for all species as they move back to nursery zone depths with maturity

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