

Salmon Food Habits Studies in the Bering Sea, 1960 to Present

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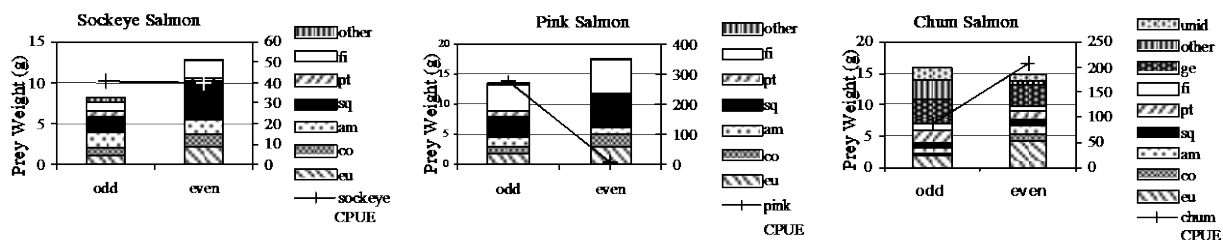
Salmon food habits studies are important to BASIS research because they help identify salmon density-dependent effects on growth and survival and can be used for food web models (NPAFC 2001). Since the 1960s these studies have been conducted in the western (e.g., Ito 1964; Andrievskaya 1966; Machidori 1968; Karpenko 1982a; Karpenko and Maksimenkov 1988; Chuchukalo et al. 1995; Klovach et al. 1996; Koval and Karpenko 1998; Bugaev and Shaporev 2002; Karpenko 2003; Smorodin et al. 2004), eastern (e.g., Nishiyama 1974; Straty 1974; Carlson et al. 1998; Murphy et al. 2003; Davis et al. 2004; Farley et al. 2004), and central (e.g., Kanno and Hamai 1972; Azuma 1992; Davis et al. 2000; Myers et al. 2004) Bering Sea. In this abstract, we review information on Bering Sea salmon food habits useful to BASIS researchers investigating salmon prey, diet overlap, ration, and bioenergetics.

Salmon distribution during their ocean migration has been linked to prey availability (Nishiyama 1974; Straty 1974; Carlson 1976; Karpenko 1979, 1983; Karpenko and Piskunova 1984; Sobolevskiy et al. 1994; Farley et al. 2004; Klovach and Gruzevich 2004). Review of 40 Bering Sea salmon food habits studies showed the major prey common to all species of salmon include euphausiids (*Thysanoessa*), hyperiid amphipods (*Themisto*), pteropods (*Limacina*), and juvenile squids (*Gonatopsis*, *Gonatus*, and *Berryteuthis*). Important fish prey include *Stenobranchius leucopsarus* and juvenile greenlings (*Pleurogrammus*) in basin habitats, and juvenile walleye pollock (*Theragra chalcogramma*), capelin (*Mallotus villosus*), and sand lance (*Ammodytes*) in shelf habitats. Future studies should focus on distribution and abundance of these major prey because this will improve our assessment of diet overlap and feeding competition.

In response to the biennial cycle of pink salmon abundance in the Bering Sea, density-dependent shifts in prey composition have been observed in the food habits of pink, chum, and sockeye salmon (Ito 1964; Andrievskaya 1966; Tadokoro et al. 1996; Karpenko et al. 1998; Davis 2003). During even-numbered years (low abundance of maturing pink salmon), total stomach content weight and proportions of euphausiids, copepods, fish, and squid increase in sockeye and pink salmon, and the proportion of euphausiids and other crustaceans increase in chum salmon stomach contents (Fig. 1).

Salmon diet overlaps (percent similarity index) were calculated for sockeye, chum, pink, and chinook salmon collected in the basin during the summer cruises (1991–2003) of the *Wakatake maru* (Fig. 2). Results showed a very high (> 75%) diet overlap between sockeye and pink salmon in odd- and even- numbered years. In odd-numbered years, however, diet overlaps between chum and sockeye, and chum and pink salmon were reduced. Comparing summer to fall overlaps using data collected onboard the *Northwest Explorer* in 2002 (Davis et al. 2004), indicated seasonal reduction in diet similarity between sockeye and chum salmon, and sockeye and chinook salmon (Fig. 2). In fall, overlap between sockeye and chum salmon in the Aleutian Islands was very high (> 75%), while overlap between chum and chinook salmon was moderate (28–30%) in the basin and the eastern shelf.

Fig. 1. Mean weight (g) of each prey category observed in the stomach contents of sockeye, pink, and chum salmon and mean CPUE (number of fish/50-m tan of research gillnet) observed during odd- and even-numbered years in the central Bering Sea in July, 1991–2000. eu = euphausiids, co = copepods, am = amphipods, sq = squid, pt = pteropods, fi = fish, ge = gelatinous zooplankton, unid = unidentified.



Bering Sea food habits studies have shown that prey composition shifts with salmon body size (Dell 1963; Andrievskaya 1968; Davis 2003; Dulepova and Dulepov 2003; Temnykh *et al.* 2003). In the basin, smaller sockeye and chum salmon contain a higher proportion of hyperiid amphipods than larger salmon (Fig. 3; Davis 2003). The proportion of squid in sockeye salmon increased with salmon body size, and the proportion of gelatinous zooplankton increased in chum salmon larger than 2500 g. Maturing chum salmon may consume more gelatinous zooplankton because it is easily digestible and widens their feeding niche (Dulepova and Dulepov 2003).

Fig. 2. Percent diet overlap of sockeye, chum, pink, and chinook salmon collected in the Bering Sea Basin, Aleutian Islands, and eastern Bering Sea shelf. Panel A = diet overlap in the basin for all years, summer 1991-2003; Panel B = even-numbered years, basin, summer 1992-2002; Panel C = odd-numbered years, basin, summer 1991-2003; Panel D = fall, 2002, basin; Panel E = fall, 2002, Aleutian Islands; Panel F = fall, 2002, eastern Bering Sea shelf.

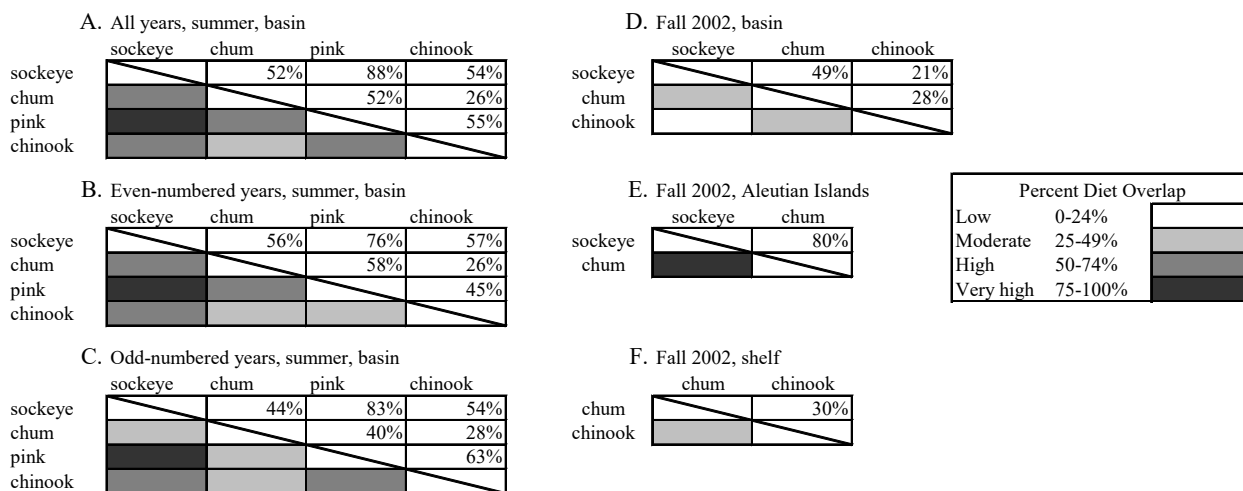
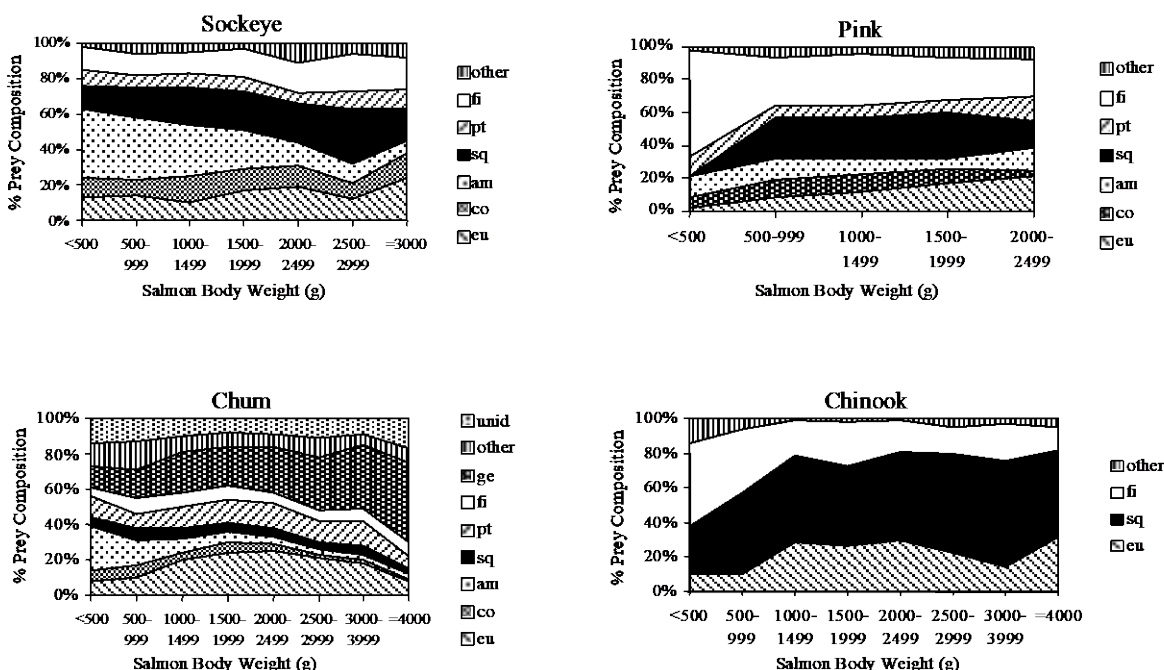


Fig. 3. Percent composition (by weight) of major prey categories collected from sockeye, chum, pink, and chinook salmon stomach contents for size groups of fish caught in the central Bering Sea basin in July, 1991-2000. Size class < 500 g represents the smallest size group for ocean age-1 fish. eu = euphausiids, co = copepods, am = amphipods, sq = squid, pt = pteropods, fi = fish, ge = gelatinous zooplankton, and unid = unidentified.



Daily ration estimates should be age- or size-specific, rather than generalized to life history stage because consumption rates shift as the fish grows (Davis *et al.* 1998). Such estimates will lend more realism to Bering Sea trophic models. Until recently, most consumption estimates for salmon were for fish described only by maturity stage. In addition, reporting ration as a percentage of body weight and energy per gram body weight would improve assessment of salmon diet quality.

Using bomb calorimetry, caloric value of some salmon prey organisms have been determined (Davis 2003). Gelatinous zooplankton (salps, ctenophores) had the lowest caloric value (< 100 cal/g wet weight, ww). Pteropods, hyperiid amphipods, smaller euphausiids, and juvenile squid (< 2 cm mantle length) had values ranging from 500–1000 cal/g ww. Caloric values of juvenile fishes, small Atka mackerel (*Pleurogrammus monopterygius*), larger euphausiids, and medium-sized squids (approximately 4 cm ML) ranged from approximately 1000 to 1500 cal/g ww, and 1500 to 2000 cal/g ww was measured from larger squid (8–9 cm ML). High values (> 2000 cal/g ww) were found in deep sea smelt (*Leuroglossus schmidti*) and *S. leucopsarus*.

Bering Sea salmon daily rations have been estimated from gut fullness and bioenergetics models (Nishiyama 1974; Karpenko 1982b; Karpenko and Nikolaeva 1989; Shuntov *et al.* 1993; Chuchukalo *et al.* 1995; Radchenko and Chigirinsky 1995; Volkov *et al.* 1995; Sobolevskiy and Senchenko 1996; Davis *et al.* 1998; Glebov 1998; Walker *et al.* 2000; Temnykh *et al.* 2003; Radchenko and Mathisen 2004). Gut fullness can be corrected for digestion rate, which is affected by prey composition, prey size, meal size, and water temperature (Windell 1978; Ney 1990). However, this method requires frequent sampling (approximately every 3 hrs) and assumes stomach contents measure food consumed. Because gut evacuation and feeding occur simultaneously, stomach contents at the end of the feeding period can underestimate the amount consumed (Elliott and Persson 1978). The bioenergetics approach uses a balanced energy budget. The Winberg bioenergetics model assumes waste and food processing costs are fixed proportions of consumption, and active metabolism is a multiple of standard metabolism (Ney 1990). The Wisconsin bioenergetics model estimates consumption as a proportion of maximum consumption of a fish at any weight or temperature and could provide relative consumption or growth estimates under differing conditions of temperature and prey availability (Ney 1990). Future bioenergetics models can simulate growth potential based on temperature predictions from Bering Sea climate models and improve our assessment of potential effects of climate change on salmon food habits and growth.

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