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A review of studies on the ringed, Caspian, and Baikal seals (*Pusa hispida*, *P. caspica*, and *P. sibirica*)

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The ringed seal (*Pusa hispida*), Baikal seal (*P. sibirica*) and Caspian seal (*P. caspica*) have common features like small size, delicate skull and breeding on fast ice, and are united in the genus *Pusa*. Five subspecies of the ringed seal are distributed in the Arctic Ocean and adjacent areas, while Baikal and Caspian seals are isolated in Lake Baikal and Caspian Sea, respectively. Since 1991, biological and environmental studies have been conducted under the Japan-Russia cooperative research programme, and various new information on the genus has been obtained. Mass die-off of the three species has often occurred in these several decades. They face bleak prospect of survival due to human activities such as over-harvesting, destruction of habitats, pollution by hazardous man-made chemicals (PCBs, DDTs, HCHs, etc.). This study is to review the most recent scientific information of the three species as well as the historical information in terms of morphology and ecology, age, growth, pollution, and population size.

Key words: the ringed seal, Caspian seal, Baikal seal, morphology, ecology, pollution, population size

INTRODUCTION

Russian researchers have published many results of studies concerning the taxonomy, distribution and ecology of the ringed seal (*Pusa hispida*), Baikal seal (*P. sibirica*) and Caspian seal (*P. caspica*). For these several decades, mass die-off of the three species has often occurred. They face bleak prospect of survival due to human activities such as over-harvesting, destruction of habitats, pollution by hazardous man-made chemicals (PCBs, DDTs, HCHs, etc.). Since 1991 Japanese research teams have conducted several expeditions under the Japan-Russia cooperative research programme (Numachi 1994, Miyazaki 1997, 1999). Numerous scientific results were obtained during these expeditions and some of them have been published. This review aims to clarify taxonomic relationship of three species in the genus *Pusa*, to improve knowledge on their morphological and ecological characteristics, and to monitor the environmental condition in their habitats polluted by hazardous man-made chemicals.

THREE SPECIES OF THE GENUS *PUSA*

The ringed seal, Baikal seal and Caspian seal have common features like small size, delicate skull and breeding on fast ice. Scheffer (1958) raised *Pusa* including these three species to genetic rank, but Burns and Fay (1970) have shown that they deserve only subgeneric rank. In this paper, I follow opinion of Rice (1998), that *Pusa* is generic name of these three species. Baikal seals and Caspian seals are distributed in Lake Baikal and the Caspian Sea, respectively. The ringed seal inhabits circumpolar Arctic coasts with a broad geographical distribution, and is found wherever there is open water in the fast ice, even as far as the North Pole, and in fjords and bays, but rarely in the open sea or on floating pack ice (King 1964). Although numerous populations and/or subspecies have been reported for the ringed seal, at present 5 distinct subspecies are usually recognized: *Pusa hispida hispida* from the Arctic Ocean and the confluent Bering Sea, *P. h. ochotensis* from the Sea of Okhotsk, *P. h. saimensis* from Lake Saimaa, *P. h. ladogensis* from Lake Ladoga, and *P. h. botnica* from the Baltic Sea (Fig. 1).

MORPHOLOGY

***Color pattern*:** Baikal seals, which don't have distinct spots, are uniform dark silver grey dorsally and light yellowish grey ventrally (Fig. 2). Caspian seals are irregularly spotted with brown or black against a light greyish yellow background (Fig. 3). The spots are sometime encircled by light colored rings. In the ringed seal, grey-white rings are found on the generally gray backs, and the belly is usually silver and lacking dark spots (Fig. 4). The rings are separate or somewhat fused together. The pups of these three species are born with a white woolly natal lanugo. This lanugo is considerably finer and longer than that of the two other northern phocids, the spotted seal (*Phoca largha*) and ribbon seal (*Phoca fasciata*) (Frost and Lowry 1981).

***Skull morphology*:** Comparison of skull morphology indicates that Baikal seals have greater length of jugal, and narrower least interorbital width and width of nasals at the maxillo-frontal suture than Caspian seals. On the other hand, in the ringed seal, characters relating to skull width, width of bulla and greatest length of bulla show larger values, while characters relating to condylobasal length and width of snout at canines show smaller ones compared to the other two species (Koyama et al.1997). Canonical discriminant analysis was performed using 14 characters with no sexual differences. All the five subspecies of the ringed seal, which are separated each other, are clearly distinguished from Baikal and Caspian seals (Koyama et al. 1997). Cluster analyses by neighbor-joining method and the UPGMA method using Mahalanobis distance suggest that Baikal seals have closer affinity with the ringed seal than Caspian seals (Koyama et al. 1997). This relationship coincides well with sequence analysis using mitochondrial DNA (Sasaki and Numachi 1997).

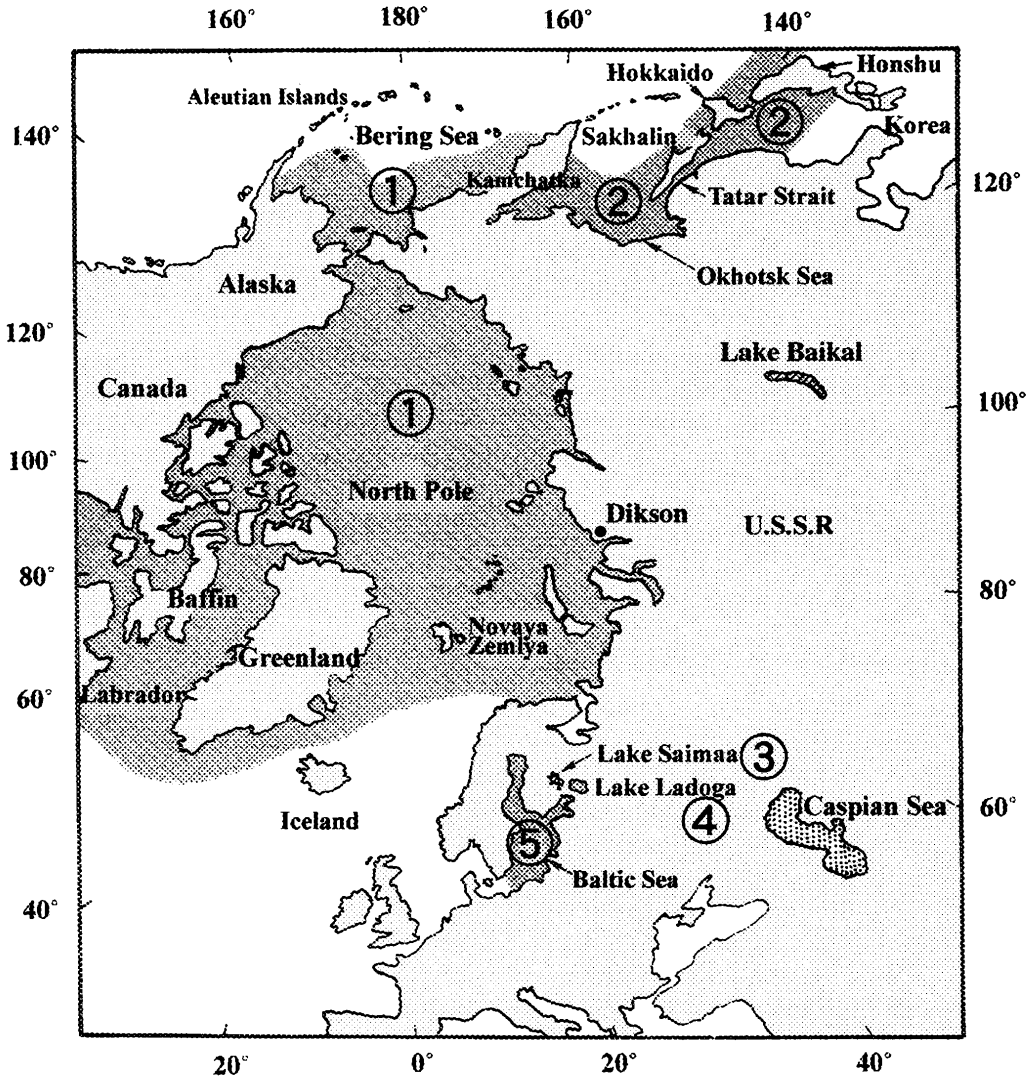

Fig. 1. Distribution of the ringed seal (dark), Caspian seal (dots) and Baikal seal (stripes) (redrawn from King, 1964). Numbers indicate subspecies of the ringed seal: 1, *Pusa hispida hispida*; 2, *P. h. ochotensis*; 3, *P. h. saimensis*; 4, *P. h. ladogensis*; 5, *P. h. botnica*.

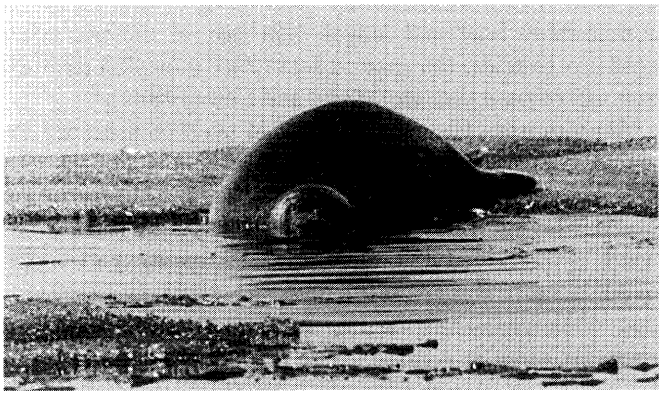

Fig. 2. Adult Baikal seal on ice, Lake Baikal. (Photograph: S. Tanabe)

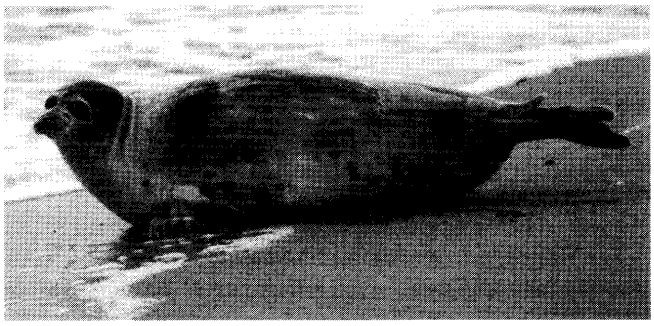

Fig. 3. Caspian seal on the Pearl Island, northwestern North Caspian Sea.

AGE AND GROWTH

The maximum known age in both sexes in Baikal seals is 56 years for females and 52 for males (Pastukhov 1993). According to Amano et al. (2000), 73 Baikal seals collected in 1992 ranged from 0.25 to 35.5 years old (females: 0.25–24.5, males: 0.5–35.5). In 118 Caspian seals collected from Pearl Island (45°01′N, 48°19′E) in the western North Caspian Sea, age ranged from 0.5 to 43.5 years (females: 0.5–43.5, males: 0.5–22.5) (Miyazaki 2000a). Maximum known age for the ringed seal is 43 (McLaren 1958). The 51 ringed seals collected at Dikson (73°34′N, 80°32′E) on the coast of Arctic Ocean in 1995 ranged from 0.5 to 19.5 years old (females: 0.5–19.5, males: 1.5–8.5) (Koyama et al. 1997).

Growth in body length of Baikal seals appears to cease at around the age of 15 years (Amano et al. 2000). The seals may continue to grow for 8–9 years after the age of sexual maturity (6 years old for females, 7 for males). Asymptotic

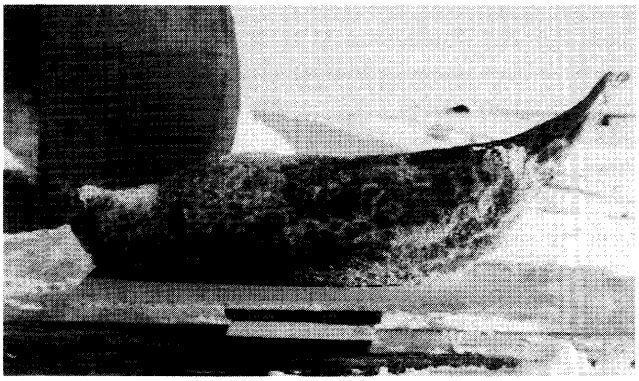

Fig. 4. Ringed seal at Dikson, the Arctic Ocean.

body length of males is 140 cm and is larger than that (130 cm) of females by 10 cm. In Caspian seals growth in body length appears to cease at around the age of 10 years, which is close to the age of sexual maturity. Asymptotic body length of males is 118 cm and is larger than that (111 cm) of females by 7 cm. McLaren (1958) reported that growth of ringed seals continues throughout the first 8–10 years of life. About 86% of final body length is attained by sexual maturity at 6–8 years. Average adult lengths for the ringed seal vary from 121 cm in the Chukchi Sea to 128.5 cm in the Bering Sea (Fedoseev 1975) and 135 cm in the Canadian Arctic (McLaren 1958).

ECOLOGY

***Behavior*:** Movements and dive patterns of Baikal seals appear to be primarily associated with seasonal prey movements of their primary diet, golomyanka and sculpins, and secondarily correlated with patterns of ice formation and thaw. Most dives of juveniles are to depths of 10–50 m, although a few exceed 300 m (Stewart et al. 1996). Dives may last between 2 and 6 minutes but a few dives exceed 40 minutes.

For two adult male Caspian seals, most dives were less than 50 m in depth while a few exceeded 200 m. Dives were mostly less than 50 second long but some exceeded 200 seconds (Miyazaki 2000b).

***Reproduction*:** Most Baikal seals attain sexual maturity at 6 years in females and 7 years in males (Thomas 1982). Newborn pups are 65 cm in body length and 4.1 kg in body weight on average. A rather high rate of twinning (4% of annual births) is exhibited compared to other seals (Pastukhov 1968a, 1968b). Mating may occur underwater in March at about the time mothers wean their pups (Pastukhov 1975). Mothers nurse the pups in the birthing lair. The lactation period is estimated as 2–3 months. The mating system is assumed to be polygamous with little or no pair bonding. In winter, when Lake Baikal is covered with ice of average 80–90 cm in thickness with a maximum of 1.5 m, seals are sighted in all areas of the lake and adjacent to breathing holes on the ice. In Baikal seals of 7 years or older, 84% of females gave birth to pup yearly (Patstukhov 1993).

Caspian seal pups are born on the ice from the middle of January to the end of February and are about 60 cm in body length. Mating takes place between the end of February and the middle of March. Sexual maturity is attained at 4–6 years in females and 6 years in males (Ognev 1935, Fedoseev 1976). The pregnancy rate of Caspian seals over 9 years was 31.3% (N=16) in 1993 and 20% (N=30) in 1997 and 1998 (Miyazaki 2000a).

Ringed seal pups, which are born between the middle of March and middle of April, are on average 65 cm in body length and about 4.5 kg in body weight. They are always born on shore-fast ice, either in a lair under the snow, excavated by the mother, or in a natural hollow in the ice. Ringed seals attain sexual maturity at 6–7 years old in both sexes with wide geographical variation from 3–5 years for *P. hispida botnica* to 6–10 years for *P. hispida hispida* (Frost and Lowry 1981). The peak of mating activity probably occurs in mid-April, shortly after parturition and while the female is still lactating (King 1964). The lactation period is nearly two months. In the ringed seals, pregnancy rates of sexually mature females vary geographically: 91–92% in the Baffin Island area (McLaren 1958, Mansfield 1970), 86% in the southern Chukchi Sea (Johnson et al. 1966), and 53% in Alaska waters in 1975–77 (Ognev 1935, Frost and Lowry 1981).

***Food*:** Baikal seals feed mainly on four fish species: the greater golomyanka (*Comephorus baicalensis*), the lesser golomyanka (*C. dybowskii*), the Baikal yellowfin sculpin (*Cottocomephorus grewingki*), and the longfin sculpin (*C. inermis*), all of which are of no commercial value. In captivity, an adult Baikal seal consumed up to 5.6 kg of fish per day (Pastukhov et al. 1969).

Caspian seals in the northern Caspian Sea feed on *Clupeonella engrauliformis*, *C. grimmi*, *C. delicata caspia*, Gobiidae, *Rutilus rutilus caspicus*, *Atherina mochon pontica*, *Lucioperca lucioperca*, other fish species, and crustaceans (Khuraskin and Pochtoyeva 1997). It is estimated that an adult Caspian seal takes 2–3 kg fish per day, or approximately 1 ton of fish per year.

Ringed seals feed on small fish and also on a wide variety of small pelagic amphipods, euphausians and other crustaceans. Seventy-two food species were identified in the stomachs of seals from the eastern Canadian Arctic. In shallow, inshore waters the seals were feeding near the bottom, chiefly on polar cod (*Boreogadus saida*) and on the small crustacean *Mysis*, while those in the deeper offshore waters were catching the planktonic amphipod *Themisto libellula* (King 1964).

***Parasites*:** Baikal seals have two common parasites, a louse (*Echinophthirius horridus baicalensis*) and a nematode (*Contracaecum osculatum baicalensis*) (Thomas 1982). Lice commonly occur above the eyes, under the chin, and under the foreflipper. Nematodes infest the stomach and intestine. According to Krylov (1990), the most pathogenic helminth that parasitizes to Caspian seals is a nematode (*Pseudamphistomum truncatum*). Fourteen percent of Caspian seals, which died near the mouths of Volga and Ural River in the northern Caspian, were heavily infested with this parasite.

POLLUTION

***Heavy metals*:** Among trace elements (Fe, Mn, Zn, Cu, Ni, Cd, Co and Hg) in Baikal seals, average level of Fe (200 μg/g in wet weight) in an adult male Baikal seal (19.5 years) was the highest, followed by Zn (25 μg/g), Cu

(0.45 μg/g), Mn (0.16 μg/g), Hg (0.14 μg/g), Ni (0.029 μg/g), Cd (0.007 μg/g) and Co (not detected) in that order (Watanabe et al. 1996). Some elements like Fe, Zn, Cu and Hg might be excreted by hair. Contaminant levels of Hg and Cd were 0.25 and 0.003 μg/g in the muscle, 2.3 and 0.28 μg/g in liver, 1.8 and 2.0 μg/g in kidney, and 0.008–0.034 and 0.007–0.037 μg/g in main fish for their food, respectively. The level of both Hg and Cd in Baikal seals is lower than that of other seals collected from polluted areas as the Bering Sea (Dietz et al. 1990, Frank et al. 1992) and off the UK coast (Law et al. 1991, 1992).

***Organochlorines*:** Levels of DDTs and PCBs in blubber of Baikal seals, of which fat content was 87%, ranged from 4.9 to 160 μg/g and 3.5 to 64 μg/g on a lipid weight basis, respectively (Nakata et al. 1995). Concentrations of CHLs (0.22 to 1.9 μg/g) and HCHs (0.028 to 0.14 μg/g) were approximately one or three orders of magnitude lower than those of DDTs and PCBs. Based on comparison of total burden between adult males and females, an adult female Baikal seal appeared to transfer about 20% of the total DDTs and 14% of the total PCBs to pup during a reproductive process. Concentrations of mono- and di-*ortho* coplanar congeners ranged from 12 to 41 ng/g wet wt. (average: 23 ng/g) for IUPAC 77, 23 to 5.9 ng/g (3.5 ng/g) for 126 and 0.20 to 0.70 ng/g (0.37 ng/g) for 169 in adult males. Comparison of 2, 3, 7, 8-TCDD toxic equivalents (TEQ) of non-, mono-, and di-*ortho* congeners in Baikal seals suggests higher enrichment of mono-*ortho* congeners, particularly IUPAC 105 and 118 contribute significantly to the total TEQs in Baikal seals (Nakata et al. 1997).

In Caspian seals, DDTs were the dominant chemicals ranging from 5.6 μg/g to 88 μg/g on wet weight, followed by PCBs (2.2–2.3 μg/g), HCHs (0.13–2.0 μg/g), CHLs (63–500 ng/g), and HCB (2.4–77 ng/g) (Watanabe et al. 1999). In the adult Caspian seal there is less sexual difference in organochlorine contamination levels than two other species. Average concentrations in prey fish such as *Rutilus* sp. were 0.033 μg/g for PCBs, 0.018 μg/g for DDTs, 0.055 μg/g for HCHs, 0.0011 μg/g for CHLs, and 0.0008 μg/g for HCB. These chemicals in Caspian seals are accumulated at about 10–1000 times higher than those in their prey fish.

Contamination levels of PCBs, DDTs and HCHs in the ringed seal collected at Dikson on the coast of Arctic Ocean were 4.2, 3.6 and 0.18 μg/g on wet weight, respectively (Nakata et al. 1998).

Baikal seals are highly polluted by PCBs and DDTs but less by HCHs, when compared with Caspian seals and the ringed seals.

POPULATION SIZE

Population of Baikal seals in 1971 to 1978 was estimated to be between 68,000 and 70,000 animals (Pastukhov 1978a). Number of seals taken annually from the population was about 2,000 to 9,000 before 1917, about 6,000 in 1930, and between 5,000 and 6,000 thereafter (Pastukhov 1976, 1978b). In 1987–1988, an outbreak of morbillivirus infection resulted in a large mass die-off of Baikal seals (Grachev et al. 1989). Another mass die-off of Baikal seals also occurred in 1998.

Caspian seal population has declined from about one million animals in the early 20th century to 360,000–400,000 in the late 1980s (Krylov 1990). According to Khuraskin and Pochtoyeva (1997), 115,000–174,000 animals have been annually hunted since the early 19th century. It was recorded that a total of 86,000 seals were killed in 1966. From 1970 the seal hunting on the northern ice was limited to a catch of 20,000–25,000 pups. In the spring of 1997 and 2000, a mass die-off of several thousands seals occurred, respectively.

A minimum population estimate for *P. hispida hispida* is 2.5 million (Bychkov 1971), although there are many uncertainties in estimation method, survey season, survey design, data analysis and so on. Population size was estimated at 800,000–1,000,000 for *P. hispida ochotensis* (Bychkov 1971), 10,000–50,000 for *P. hispida botnica* (Scheffer 1958), 2,000–5,000 for *P. hispida saimensis* (Scheffer, 1958), 5,000–10,000 for *P. hispida ladogensis* (Scheffer 1958). Many thousands of ringed seals are caught annually in all areas where they occur, mostly for their skins, which are used for leather or decorative fur, and also for blubber (King 1964). Mass die-off of ringed seals was recorded in 1960s in the Baltic Sea and the North Sea (Helle 1980, Bergman and Olsson 1986).

SUMMARY AND FUTURE DIRECTION

In the present review, the knowledge on morphological and ecological characteristics of the three species in the genus *Pusa*, and their taxonomic relationship are improved. It is also reported that these three species face severe environmental condition polluted by man-made chemicals like organochlorine compounds (PCBs, DDTs, HCHs, etc.). Closed areas such as Lake Baikal, Caspian Sea and Arctic Ocean became much polluted zones, because the developed countries in the northern Hemisphere had produced a lot of man-made chemicals, which were transported from the land source into lakes and oceans through both rivers and atmosphere. Especially, HCHs are largely transported by atmosphere into the Arctic Ocean from tropical areas, where HCHs are still used as pesticide although both production and use of HCHs were banned in the developed countries in 1970s. Higher contamination of these chemicals is suspected to cause the impairment of immune function, reproductive disorder and morbillivirus infection, all of which lead population decrease. Distemper virus infection is considered as the primary cause of mass die-off of Baikal seals in 1987–88 and 1998, and Caspian seals in 1997 and 2000 (Grachev et al. 1989, Osterhaus et al. 1989, Forsyth et al. 1998, Kennedy et al. 2000). Thus, as future direction, the systematic scientific research of these three species and the environmental study should be conducted under the international cooperative research project in order to estimate current population size and accurate life history parameters, and to monitor environmental condition.

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ワモンアザラシ，カスピカイアザラシおよびバイカルアザラシ研究の概説

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ワモンアザラシ (*Pusa hispida*)，バイカルアザラシ (*Pusa sibirica*) およびカスピカイアザラシ (*Pusa caspica*) は，小さな体，華奢な頭骨，冬季氷上生活することで共通しており，*Pusa*属にまとめられている．ワモンアザラシは北極圏に5亜種が生息しており，バイカルアザラシとカスピカイアザラシはそれぞれバイカル湖とカスピ海に隔離されている．1991年以来，これら3種の生物および環境に関する日本とロシアの共同研究が実施され，多くの知見が蓄積されてきた．これらの種類では，最近数十年間にしばしば大量死が起き，個体数の減少が顕著である．彼らは，乱獲，生息環境の破壊，汚染などの人間活動により直接影響を受け，深刻な状況に直面している．本稿では，上記3種に関する形態および生態的特徴，年齢と成長，人工有害化学物質（PCBs, DDTs, HCHsなど）による汚染および個体数の変化について，これまでの情報に最新の知見を加えて概説する．

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