How to evaluate and decrease ecological risk and impact of endocrine disrupting chemicals

Hiroyuki MATSUDA[1]

[1] Population Dynamics of Marine Organisms, Ocean Research Institute, University of Tokyo, CREST, Japan Science and Technology Corporation, 1-15-1 Minamidai, Nakano-ku, Tokyo 164-8639 Japan, email: matsuda@ori.u-tokyo.ac.jp.

Abstract

I and my colleagues consider a new method to evaluate ecological risk and impact in continuously declining populations. For these populations, mean time to extinction depends on the current population size, rate of population decrease and its variance. Using magnitude of increase in the rate of population decrease or reduction of current population size by human impact, I can estimate ecological impact on these populations. I compare between ecological impacts of overexploitation on tunas, habitat size reduction on vascular plants and possible reduction in reproduction rate on sea lions by endocrine disrupting chemicals (EDCs). In spite of many uncertainty in effects of EDCs on reproduction rate of marine animals, I can expect that contamination by EDCs decreases population size in future generations, and magnitude of these effects are very large.

Ecological Impacts Based on Extinction Risk

Loss of longevity by an environmental chemical is a useful indicator of environmental impact of this chemical in human health. For a similar reason, I may define ecological risk for a species based on mean time until that species goes extinct.

Most of biological species are threatened due to rapid population reduction. In

1996, 113 marine fish species are listed in Red List. Among these, 83 taxa are listed solely by population reduction (see Matsuda et al. 1997). Major reason of population declining in marine fish species may be overexploitation. About two-thirds of marine bioresources are either depleted (6%), overexploited (16%) or fully-heavily exploited (44%) (FAO 1994). In 1997, Japan Agency of Environment (JAE) revised red list of Japanese vascular plants (Yahara et al., 1998). About one-fifth taxa of Japanese native vascular plants, 1428 taxa, are threatened, which listing is based on combination of population size and population declining rate. Major reason of population decline in these plants may be habitat size reduction and illegal collecting.

Suppose a taxon of which population size is still large enough and is rapidly decreasing. There are many examples of such taxa in terrestrial and marine, plants and animals. For example, southern bluefin tuna (*Thunnus maccoyii*, Matsuda et al. 1997) and Japanese bellflower (*Platycodon grandiflorum*, Yahara et al. 1998), which were listed in threatened species respectively by IUCN in 1996 and JAE in 1997. Extinction probability of these taxa within the next 10 years or 3 generations is negligible, in spite of the fact that extinction probability of these taxa within the next one century is remarkably large, if recent rate of population decrease will continue in the future (Matsuda et al. 1998).

Extinction Impacts of Overexploitation and Habitat Size Reduction

Southern bluefin tuna is either threatened or nearly threatened by overexploitation since 1960s. Average catches in 1950s, 1960s, 1970s, 1980s and 1990s are respectively 15606, 59930, 42625, 33605 and 13302 tons. Average rates of exploitation in 1980s and 1990s are respectively about 7% and 11%. The average rate of population increase, denoted by r^*, is defined as mean of $r_t = \log(N_t/N_{t+1})$, where N_t is the number of mature individuals in year t. For this tuna, r^* is -0.056 ± 0.039 during 1965-1974 and -0.109 ± 0.043 during 1985-1994 (see Matsuda et al. 1997). Although the tuna had been exploited during 1965-1975, I can estimate loss of mean time to extinction due to increase in fishing pressure during 1985-1994. In accordance with Lande and Orzack (1988), mean time to extinction, T, is

$$T = \int_0^{\infty} \frac{tx_p}{\sqrt{2\pi\sigma^2 t^3}} \exp\left[-\frac{(x_p + r^* t)^2}{2\sigma^2 t} \right] dt,$$

where $x_p = \log(N_p/N_{crit})$, N_{crit} is critical size (=500 for tunas, see Matsuda et al. 1997), σ is standard deviation of r_t.

Mean time to extinction (T) of southern bluefin tuna is 90.1 years if $r^*= -0.056\pm0.039$, while T is 61.8 years if $r^*= -0.109\pm0.043$. Therefore, loss of mean time to extinction by recent increase in the rate of exploitation is 29.3 years.

Although I could assume that mean longevity of any person is identical, mean time to extinction depends on taxon. It is difficult to compare loss of mean time to extinction between threatened species and secure species. Therefore I define increment of extinction risk as $1/T_1$-$1/T_0$ where T_0 and T_1 are mean time to extinction of a species without and with a specific human impact, respectively. If I consider that T_0 and T_1 are respectively mean time to extinction of the tuna under exploitation level during 1965-1974 and during 1985-1994, increment of extinction risk of the tuna by increment of overexploitation during 1985-1994 is 0.016-0.011=0.5%.

If the rate of population increase in the tuna without exploitation is nonnegative, mean time to extinction is definitely longer than 1 billion years. Therefore, loss of mean time to extinction is also very large. If we consider T_0 as mean time to extinction without any exploitation, increment of extinction risk is 0.016-0=1.6%.

I consider that loss of mean time to extinction from large enough (>10^9 years) to 100 years is almost the same level of impact as loss of mean time to extinction from 100 years to 50 years, and from 11 years to 10 years. If this is reasonable, I can compare loss of mean time to extinction between a variety of taxa.

Population size of Japanese bellflower is still large and rapidly decreasing. Estimated mean time to extinction is T_0=70.8 years (Matsuda et al., unpublished). Suppose an additional habitat size reduction that reduce the biggest habitat of the bellflower. If this reduction is considered to be not repeated, I can evaluate ecological impact of this reduction on the bellflower by (1) no change of population declining rate and (2) decrease of current population size. After loss of the biggest habitat, estimated mean time to extinction is T_1=70.5 years. Therefore, increment of extinction risk by loss of the biggest habitat is 0.006%.

I consider another example, an endangered orchid, *Cypripedium macranthum speciosum*. This orchid is listed as endangered and T_0=15.6 years. If an additional and unrepeatable habitat size reduction reduces the smallest habitat, T_1=15.3 years and increment of extinction risk is 0.13%.

Increment of extinction risk may give a measurement of ecological impact. I can compare ecological impact of overexploitation in southern bluefin tuna with that of habitat size reduction in Japanese bellflower. The above evaluation suggests that the former is much larger than the latter. This is probably because continuous overexploitation is much more effective than transient reduction of habitat.

I can also compare ecological impact of loss of the smallest habitat in the endangered orchid with that of loss of the biggest habitat in the vulnerable bellflower. The above evaluation suggests that the former is much larger than the latter. This is probably because mean time to extinction in vascular plants depends on the number of habitats, rather than total population size. It is likely that effect of loss of one habitat on mean time to extinction increases with the number of habitats.

Characteristic Properties of Reproduction Impacts on Extinction Risk

For most of rapidly declining taxa, it has been considered that cause of population decline is either habitat size reduction or overexploitation. However, endocrine disrupting chemicals (EDCs) may also be an important factor of rapid population decrease, at least in marine animals. For some dolphin, negative relationship between the testosterone levels and PCBs and DDE are known (see Tanabe 1998).

Despite of small concentration of EDCs in the environment, (1) biological concentration via food chain increases EDC concentrations in marine mammals, (2) EDC concentrations in the ocean are often larger than those in the air, (3) marine mammals have large fat tissue, in which EDC concentrations are large enough, (4) vertical transportation of PCB from mother to offspring via lactation, and (5) cetaceans and seals have weak or no metabolic systems for organochlorines (see Tanabe 1998).

EDCs may eliminate reproduction in marine animals rather than survival rate, because of affecting sex hormone balance. There are some difference in extinction risk between decrease of annual survival rate and that of reproduction rate. Since cumulative survival rate at a given age depends on product of annual survival rate until this age, 10% increase of annual mortality gives a larger effect on extinction risk than 10% decrease of reproduction rate.

York (1994) estimated age-specific annual mortality and reproduction rate in northern sea lions (*Eumetopias jubatus*) at western Gulf of Alaska. The rate of population increase without catch or bycatch is 0.998 per year. If annual survival rate decreases by 10% for any age, the rate of population increase is 0.899, which is exactly 10% decrease of 0.998. In contrast, if reproduction rate decreases by 10% for any age, the rate of population increase is 0.989, which is 1.1% decrease of 0.998.

However, reduction in reproduction rate results in decrease in the number of mature individuals with a time-lag from birth to maturation. Figure 1 illustrates population decrease under reduction of reproduction rate (left panel). For three lines in the left panel, rates of population increase after reaching stable age structure are respectively 0.848, 0.888 and 0.933 (from bottom to top). I used initial population size (about 3000) of the Kuril Islands population of Steller sea lion in 1989 and assumed that reproduction and survival rate are identical to northern sea lions reported by York (1994), as assumed by Takahashi and Wada (1998).

Even the case of 90% reduction of reproduction rate, population is not very rapidly decreasing. This is because physiological longevity of marine mammals is often long. Even in the case of 100% reduction in reproduction rate, the population never goes extinct until at least one mature individuals survives. In contrast, the population never persists in the next year in the case of 100% increase in mortality rate. In spite of the same rate of population decrease after reaching stable age-structure (90% reduction in reproduction rate and 15% reduction in annual survival rate), age structures of these populations in 10 years after 1989 are very different from each other (right panel in Fig. 1).

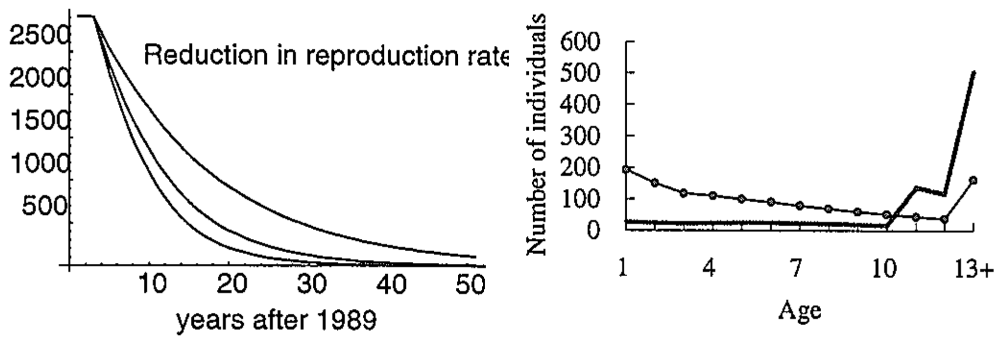

Fig. 1. Simulations of population declining (left panel) and age structures in 10 years after 1989 (right panel). Vertical axis in left panel is respectively the number of mature individuals (3 years old and older). Three dotted lines in left panel show cases of 90%, 75% and 50% reduction of reproduction rate (from bottom to top). Two lines in right panel show age structure under reduction in reproduction rate (bold line) and reduction in annual survival rate (line with circles).

Increment of Extinction Risk by Reduction in Reproduction Rate

The Kuril Islands population of Steller sea lions is decreasing and is listed as endangered, because estimates of population size is rapidly decreasing. The population size was about 20,000 in 1964 and 4,000 in 1989 (see Takahashi and

Watanabe 1998). Average rate of population decrease ($r^*=\log(N_{1989}/N_{1964})/45$) is –0.614 and its SD is 0.560. If critical size of this population (N_{crit}) is assumed to be 50, mean time from population size in 1989 to extinction of this sea lions is 66.1 years. If r^* = –0.00166 as is obtained by York's (1994) life history parameters, mean time to extinction is 2445.5 years. Therefore, increment in extinction risk of catch and bycatch by fishers is 1/66.1–1/2445.5=1.4%. This is almost the same as ecological impact of overexploitation during 1985-1994 on southern bluefin tuna.

Magnitude of reduction in reproduction rate caused by EDCs is not known. However, there is some evidence of reduction in reproduction rate for several gastropods. In some snail, it is reported that 97% of females is sterile due to sex hormone problem. If EDCs reduce reproduction rate of marine mammals, effect of EDCs on reduction in mean time to extinction could be very large. If reproduction rate of Steller sea lions decreased by 90%, the rate of population increase r^* will be -0.227 and mean time to extinction is about 20 years. Therefore increment of extinction risk is 1/20-1/66.1=3.5%. If reproduction rate decreased by 75% and 50%, mean time to extinction is respectively 24 years and 33 years, and increment of extinction risk is respectively 2.7% and 1.5%. All of these results are remarkably large.

In addition, declining populations due to reduction of reproduction rate usually have few immature individuals. Most of this population are older individuals. Age structure of these population is skewed. This suggests that conservation action of these population is very difficult, after EDC concentrations are large enough to affect reproduction rate of marine animals. Even now, it may have been too late.

Although I ignored reduction of survival rate caused by EDCs, some reports suggested effects of EDCs on reduction of survival rate of marine mammals maybe since 1950s (see Tanabe 1998). I do not know magnitude of reduction in survival rate. I do not know whether the survival rate of marine mammals has begun to decrease due to EDCs or not.

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