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Hagfish Conservation Needed in Taiwan

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Abstract
Hagfish is the most primitive craniate and is a sister group to vertebrates. The hagfish attracts the interest of fishery biologists and ichthyologists due to its commercial utilization (e.g., for leather products and food) and its diverse specializations. There are about 60 hagfish worldwide species including the shallow-water Eptatretineae and deep-sea Myxininae. Taiwan is a region with a high biodiversity of hagfish species. Eleven species in the genera *Myxine, Eptatretus* and *Paramyxine* have been recorded in this region, and they have been the subject of numerous scientific studies, focusing on topics including phylogeny, photo-response behavior, reproductive biology, heavy metal accumulation and muscle proteomics and metabolomics. Based on morphological and molecular evidence, we found that *Paramyxine cheni* and *Eptatretus rubicundus* are the most primitive species in the subfamily Eptatretineae, and their conservation deserves special attention. In addition, the overfishing of Taiwanese hagfish has also been noted and is becoming a challenging question with hagfish research in Taiwan.

Key words: conservation, hagfish, phylogeny, Taiwan

1. Introduction

In the process of the evolution of vertebrates, the notochord is an important element in the transition from invertebrates to vertebrates. The notochord is a flexible, rod-shaped structure found in the embryos of all chordates. In some chordates, it persists throughout life as the main axial support of the body, while in most vertebrates it becomes the vertebral body of the vertebral column. The notochord is positioned ventrally to the neural tube. In higher vertebrates, the notochord only appears in the embryonic stage, and is replaced by the vertebra during growth. Hagfish are classified as Vertebrata, but they only have notochord, and do not possess vertebra.

2. Hagfishes Worldwide

Hagfish are distributed worldwide, except for the Arctic and Atlantic areas. And in total there are about sixty species recorded worldwide. The subfamily Myxininae consists of 4 genera (Myxine, Neomyxine, Nemamyxine and Notomyxine), and several special ecological and physiological characteristics appearing in hagfish attract attention from related studies due to the hagfish's special position in the evolutionary linage.

Lamprey and hagfish are jawless and they are classified as belonging to Cyclostomata. In contrast to hagfish, lamprey have specialized vertebra, but they also share some morphological characteristics, thus the relationship between hagfish, lamprey, and vertebrates is still not clear from the morphological studies (Løvtrup, 1977) or molecular evidence (Takezaki *et al.,* 2004). Because it is very difficult to collect the hagfish embryo, studies of hagfish development remain limited. In recent years, the use of an Evo-Devo (evolutionary developmental biology) approach to investigate the development of hagfish embryos by Ota *et al*. (2007) has been big breakthrough. Table 1 shows the related research on hagfish embryos in recent years (adapted from Gorbman 1997). From the reports obtained, we can understand that studies of hagfish embryos advance slowly. Ota *et al*. (2007) collected 92 hagfish eggs of *Eptatretus bugeri* in the laboratory, but only 7 eggs were found to be developmental embryos. This suggests that hagfish can spawn in artificial conditions, but since it is difficult to obtain the embryos, they are both scarce and valuable in these studies. However, some details of the spawning process need to be clarified, for example, the question of whether

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Table 1. Published reports associated with hagfish embryos and development.

Author	Year	Target	Species
Price, G. C.	1896, 1897, 1904	General development and digestive organs	*Eptatretus stouti*
Dean, B.	1898, 1899	General development	*Eptatretus stouti*
von Kupffer, C.	1899, 1906	General and brain development	*Eptatretus stouti*
Doflein, F.	1899	General development	*Eptatretus stouti*
Worthington, J.	1905	General development	*Eptatretus stouti*
Stockard, C.	1906	Pharynx and thyroid	*Eptatretus stouti*
Conel, J. L.	1929, 1931	Brain	*Eptatretus stouti*
Neumayr, L.	1938	Brain skeleton	*Eptatretus stouti*
Holmgren, N.	1946	General development	*Myxine glutinosa*
Fernholm, B.	1969	Pituitary	*Myxine glutinosa*
Gorbman, A.	1983, 1985	Brain development	*Eptatretus stouti*
Gorbman, A.	1990	Pituitary and sexual differentiation	*Eptatretus stouti*
Ota, K. G.	2007	Neural crest	*Eptatretus burgeri*

the reproduction system was external fertilization or internal fertilization, is still a mystery.

The order Myxiniformes is thought to be monophyletic, based on molecular evidence from mitochondrial 16S ribosomal RNA (Kuo *et al*. 2003, Chen *et al*. 2005). This order consists only of the family Myxininae which is divided into 2 subfamilies, the deep-sea (more than 1000m) Myxininae and the shallow-water Eptatretinae (e.g., *E. burger*) based on morphological features (Fernholm 1998). They are noteworthy to study from an evolutionary standpoint because they represent the oldest extant clade among the craniates; in other words, they are a sister group to all vertebrates. In addition, they are scanverger; their food includes dead mamals as well as fish and invertebrates. In the food chain, they remain at a special trophic level. However, many basic questions about them srill remain unanswered.

The most detailed description about the development of hagfish embryos (Pacific hagfish, *E. stouti*) was given by Dean (1899) who collected more than 800 hagfish eggs, among which 150 contained developed embryos. He described almost almost every stage of *E. stouti* development and his study became the key reference for later studies focusing on hagfish development. However, after that, study of hagfish embryology did not progresssignificantly until Ota *et al*. (2007) studied the gene expression of neural crest on hagfish embryos.

3. Hagfishes in Taiwan

There are shallow-water and deep-sea hagfish distributed in Taiwan which as a geological region has a high biodiversity of hagfish. Three(3) genera and 11 species have been recorded(Table 2), among them 9 were Taiwan specific species, including *Paramyxine sheni, P. taiwanae, P. yangi, P. cheni, P. nelsoni, P. fernholmi* and three *Myxine* species. About seventeen percent of hagfish found in Taiwan, making it a region with a high diversity of hagfish. It is a quite convenient place to undertake hagfish related research due to the special nature of the region with its high hagfish diversity.

Despite the high diversity of hagfish in Taiwan, their distributions are restricted with hagfish found mainly in southwestern and northeastern areas. Thus in this paper, we are concerned with the conservation and protection of hagfish in Taiwan. In addition to their scientific importance, hagfish have also been used commercially. In Korea, since the 1960s, there has been significant

Table 2. Hagfishes recorded in Taiwanese waters.

Family & subfamily	Species	Specific species in Taiwan
Myxinidae		
Eptatretinae	*Paramyxine nelsoni*	V
	P. yangi	V
	P. sheni	V
	P. taiwanae	V
	P. cheni	V
	P. fernholmi	V
	Eptatretus burgeri	
	E. rubicundus	
	E. chenensis(*)	
Myxininae		
	Myxine formosana	V
	M. koui	V

**E. chenensis is collected in South China Sea*

trade in leather goods produced from tanned hagfish skin. Although the products are branded as eel skin (wallets, etc.), actually they are made from hagfish skin. In Taiwan, they are reffered to as “dragon tendona” and are mainly consumed as sea food. As shown in Figure 1, skinned hagfish are sold as food in local fish markets.

Fig. 1. Skinned hagfish are sold as food in a local fish market.

However, in recent years, according to fishers at Donggang (a township at the southwestern coast of Taiwan), the fish population there decreased dramatically due to overfishing. In addition, we also found that a local trapping fishery centered at Donggang a local trapping fishery centered at Donggang caught *M. formosana* from about 1996 to 2002. Scince 2003, *M. formosana* disappeared from the market and *E. chinensis* from the South China Sea is now being sold instead. At present, the South China Sea has become the favoredfishing ground and *E. chinensis* is the target species. This switch in major commercial species may have been the result of the shrinking of the *M. formosana* population. Enlarged eggs vary in maximum size from 20 to 70 mm depending on the species, and only 20 to 30 yolky eggs are present at a time in mature females, This fact combined with the low number of mature eggs within hagfish compared to other teleost, and a trapping rate which far exceeds the reproduction rate leads us to be conclude that the hagfish population will not be easy to replenish.

Because *P. yangi* and *P. nelsoni* are species of small size, they are not caught for commercial food, thus they are still free from the ploblems of overrfishing. According to morphological and molecular evidence, *P. cheni* and *E. rubicundus* were assumed to be the most primitive species in Eptatretinae (Figure 2; Kuo *et al.*, 2003). *E. rubicundus* is a new species recorded in 2010. These two primitive hagfish types are observed only in southwestern Taiwanease waters with their distribution being very limited. In addition, these two species are significant size with commensurate commercial values.

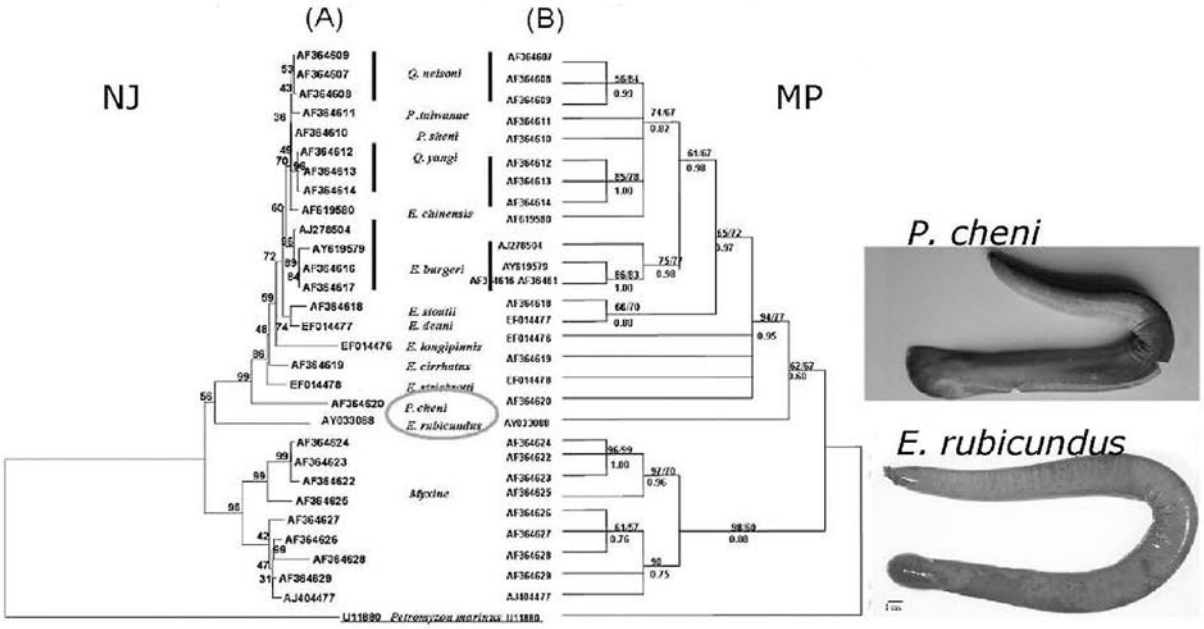

Fig. 2. Phylogenetic relationship of hagfishes based on the molecular evidences.

However, fishing activity is high in thisregion, so we think hagfish protection and conservation deserves attention.

4. Conclusion

In summary, in addition to the current scientific research, any aspects of eco-physiological mechanisms should be further investigated in hagfish, effort is required in hagfish related studies, and the conservation of hagfish should be an issur of concern. What a pity it would be if a creature containing so many mysterious secrets needing to be discovered were to become extinct before its mysteries could be revealed.

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