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Sex Characterization of Wrasses Inhabiting in the Coastal Waters of Jeju, Korea

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제주연안에 서식하는 놀래기류의 성특성

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ABSTRACT: We reviewed sex-change patterns in the wrasses *Halichoeres poecilopterus, H. tenuispinis*, *Pteragogus flagellifer*, and *Pseudolabrus sieboldi* inhabiting the coastal waters of Jeju, Korea, based on the sex distribution according to standard length and sex characteristics of the gonads. *Halichoeres poecilopterus, H. tenuispinis, Pt. flagellifer*, and *Ps. sieboldi* are protogynous hermaphroditic fish. Histological observations revealed that these wrasses are undelimited type 2 species because testicular tissue appears in most parts of the gonads during ovary degeneration. Both initial- and terminal-phase males were present in the investigated populations, indicating that *Halichoeres poecilopterus*, *H. tenuispinis,* and *Ps. sieboldi* are of the diandric type. In contrast, *Pt. flagellifer* is considered a monandric type, because all males in the investigated populations were terminal-phase males produced via sex change from functional females.

Key words: Wrasse, Sex change, Protogynous hermaphroditic fish, Undelimited type, Monandry type

요 약 : 제주 연안에 서식하는 용치놀래기, 어렝놀래기, 황놀래기, 놀래기를 대상으로 체장에 따른 성분포와 생식소의 성특성을 조직학적으로 탐색하여 성전환 양상을 비교하였다. 용치놀래기, 어렝놀래기, 황놀래기, 놀래기는 자성선숙형 자웅동체어로 조직학적 관찰결과 정소조직이 난소의 퇴화중에 생식소 전역에 출현하는 혼재형 2에 속하는 어종이었다. 용치놀래기, 황놀래기 그리고 놀래기는 1차 수컷과 2차 수컷이 존재하는 복웅성 어류이고 조사된 어렝놀래기는 암컷의 일부가 수컷으로 성전환하여 2차 수컷만이 나타나고 있어 단웅성 어류라고 생각된다.

Introduction

The sex of fish can be divided into gonochorism and hermaphrodism. Hermaphrodites can be divided into protogynous, protandrous, and synchronous types. Protogynous hermaphrodites first become sexually mature as females and later change sex to become males. Protandrous hermaphrodites first become sexually mature as males and then later change sex to become females. Synchronous hermaphrodites simultaneously function as males and females (Atz, 1964; Yamamoto, 1969). The diversity of fish sexes is a reproductive strategy for survival in marine environments.

Wrasses are protogynous hermaphroditic fish. Many studies have investigated their reproductive biology, including sex change and sexual patterns (Bruslé, 1987 Warner and Robertson, 1987), age and growth (Hashimoto et al., 1991), spawning behavior (Sakai and Kohda, 2001), and reproductive cycle ((Lee et al., 1991, 1992a, b, 1993 Candi et al., 2004). About 10 species of wrasse inhabit the waters off Jeju Island, Korea. Here, we review the sex change patterns of *Halichoeres poecilopterus, H. tenuispinis, Pteragogus flagellifer*, and *Pseudolabrus sieboldi* inhabiting the coastal waters off Jeju Island, Korea, based on the sex distribution according to standard length and sex characteristics of the gonads.

Gonadal changes during sex change

The process of sex change in the wrasse *Thalassoma duperrey* is divided into six stages based on gonadal changes (Nakamura et al., 1989): Stage 1, normal ovaries of females arefilled with vitellogenic oocytes during the breeding season; Stage 2, onset of sex change, during which the degeneration of yolky oocytes occurs; Stage 3, degeneration of peri-nucleolus oocytes; Stage 4, proliferation of Leydig cells and spermatogonia; Stage 5, onset of spermatogenesis; Stage 6, completion of testes just after sex change.

The ovaries of *T. duperrey* are filled with vitellogenic oocytes during the breeding season, but contain no spermatogenic tissue (Nakamura et al., 1989). *Thalassoma duperrey* is considered a protogynous hermaphrodite, as are *Anthias squamipinnis* (Shapiro, 1981), *H. poecilopterus* (Lee et al., 1991), *H. tenuispinis* (Lee et al., 1993), *Pt. flagellifer*(Lee et al., 1992a), and *Ps. sieboldi* (Lee et al., 1992b).

The testes of *Ps. sieboldi* primary males consist of numerous testicular lobules, and efferent sperm ducts are located at the base of the lobules (Fig. 1A). The ovary is arranged in lamellae, which extend into a central, membrane-bound ovarian cavity. The lamellae contain young oocytes and primary yolk oocytes (Fig. 1B). The gonads of sex-changing individuals consist of testicular tissue at the cortex and ovarian tissue at the medulla (Fig. 1C). A few degenerating yolk oocytes still remain in the spermatogenic gonads (Fig. 1D). The testes of terminal males following the sex change from female to male contain an ovarian cavity, and newly formed efferent sperm ducts are situated along the base of the gonads (Fig. 1E).

In many families and species, including certain labrids such as *T. duperrey*, scarids, and several synbranchids, primary and terminal males can be distinguished histologically because of distinct morphological differences between the two testis types (Liem, 1968 Harrington, 1971; Nakamura et al., 1989). However, this morphological distinction may not be as clear in all labrids (Shapiro and Rasotto, 1993). Protogynous hermaphroditic fish can be divided into two types, delimited and undelimited, according to the location of the testicular tissue during sex change (Sadovy and Shapiro, 1987). In the delimited type, the origin of testicular tissue is adjacent to ovarian tissue, and both testicular and ovarian tissue are separated by connective tissue. This type includes species of the Sparidae (D'Ancona, 1949),(Reinboth, 1962), and *Centropyge interruptus* of the Pomacanthidae (Moyer and Nakazono, 1978).

In the undelimited type, oogenesis and spermatogenesis occur simultaneously in several parts of the gonads, andovarian and testicular tissue are not separated by connective tissue. The undelimited type can be divided into two types: undelimited type 1, in which testicular tissue appears in a particular area, and undelimited type 2, in which testicular tissue appears in most parts of the gonads during ovary degeneration. Undelimited type 1 includes *Rypticus* of the Serranidae (Smith, 1965) and *Coryphopterus* of the Gobiidae (Cole, 1983). Undelimited type 2 includes *Genicanthus melanospilos* of the Pomacanthidae (Shen and Liu, 1976), Labridae (Roede, 1972; Reinboth, 1975), and Scaridae (Choat and Robertson, 1975; Bruce, 1980). *Halichoeres poecilopterus* (Lee et al., 1991), *H. tenuispinis*(Lee et al., 1993), *Pt. flagellifer* (Lee et al., 1992a), and *Ps. sieboldi* (Lee et al., 1992b) inhabiting the coastal waters off Jeju Island are considered undelimited type 2 species.

Sex steroid hormones play a critical role in the sex change of hermaphroditic fish. The predominant steroid associated with sex change in protandrous species is estradiol-17β (E_2). In contrast, 11-ketotestosterone (11-KT) plays a critical role in protogynous species (Chang and Lin, 1998; Kroon and Liley, 2000). For example, during sex change in the wrasse *T. duperrey*, plasma levels of E_2 decrease, whereas those of 11-KT increase (Nakamura et al., 1989). However, during sex change in the protogynous *Monopterus albus*, the development of interstitial Leydig cells precedes the increase in 11-KT production, and the increase in the number of Leydig cells is accompanied by an increase in 11-KT production (Chan and Phillips, 1967). Therefore, because interstitial cells such as Leydig cells are accompanied by endocrine activity according to sex change (Tang et al., 1974, 1975), the endocrine activity of Leydig cells is considered a factor in sex change (Chan and Yeung, 1983).

The degeneration of oocytes and proliferation of somatic and acidophillic interstitial cells have been observed during sex change in *H. poecilopterus* (Lee et al., 1991), *H. tenuispinis* (Lee et al., 1993), *Pt. flagellifer* (Lee et a., 1992a), and *Ps. sieboldi* (Lee et al., 1992b). This is considered evidence that the endocrine activity of interstitial cells promotes sex change.

Sex distribution according to standard length

The sex distribution according to the standard length of *H. poecilopterus* (Lee et a., 1991), *H. tenuispinis*(Lee et al., 1993), *Pt. flagellifer* (Lee et a., 1992a), and *Ps. sieboldi* (Lee et al., 1992b) is shown in Fig. 2. In *H. poecilopterus*, females (n = 41) were 10.0–17.0 cm in standard length (SL), initial males (n = 11) were 10.5–16.5 cm SL, inter-sex (n = 6) individuals were 11.0–16.0 cm SL, and terminal females (n = 23) were 11.0–18.0 cm SL (Fig. 2A). In *Pt. flagellifer*, females (n = 26) were 8.0–12.5 cm SL, inter-sex fish (n = 16) were 9.5–15.0 cm SL, and terminal females (n = 75) were 11.5–18.0 cm SL (Fig. 2B). In *Ps. sieboldi*, females (n = 56) were 9.0–17.0 cm SL, initial males (n = 5) were 13.5–16.5 cm SL, inter-sex individuals (n = 9) were 11.5–16.0 cm SL, and terminal females (n = 75) were 11.5–18.0 cm SL (Fig. 2C). In *H. tenuispinis*, females (n = 73) were 8.5–13.5 cm SL, inter-sex individuals (n = 2) were 11.0–13.0 cm SL, and terminal females (n = 14) were 10.0–13.0 cm SL (Fig. 2D).

Sex pattern of wrasses

Sex change in fish is species specific and has been reported in at least 23 families, including over 350 species (Helfman et al., 1997). Protogynous hermaphroditic species are known from the Gobiidae (Cole, 1990; Cole and Shapiro, 1992), Labridae (Nakazono and Kusen, 1991; Lee et al., 1993), Scaridae (Kusen and Nakazono, 1991), and Serranidae (Tanaka et al., 1990; Lee et al., 1993). Protandrous hermaphrodites include species from the Pomacentridae (Moyer and Nakaozono, 1978) and *Acanthopagrus schlegeli* of the Sparidae (Chang and Lin, 1998).

Protogynous hermaphroditic fish can be divided into two types, monandric and diandric, on the male developmental pathway (Reinboth, 1967). Monandric species follow a singlemale developmental pathway; all males in a population are terminal males derived exclusively from functional females via sex change. Species of this type include *Nelabrichthys ornatus* (Andrew et al., 1996), *Achoerodus viridis* (Gillanders, 1995), *Cirrhilabrus temmincki* (Kobayashi and Suzuki, 1990), *Choerodon schoenleinii* (Ebisawa et al., 1995), *C. azurio* (Nakazono and Kusen 1991), and *Calotomus japonicus*of the Scaridae (Kusen and Nakazono, 1991). Diandric species follow two male developmental pathways, i.e., initial males develop from juveniles through sexual differentiation and terminal males develop via sex change as in monandric species; both types occur within a population. Species of this type include *Thalassoma bifasciatum* (Warner and Robertson, 1978), *Cheilinus undulatus* (Donaldson and Sadovy, 2001), and scarids (Robertson and Warner, 1978).

Halichoeres poecilopterus (Lee et a., 1991), *H. tenuispinis* (Lee et al., 1993), and *Ps. sieboldi* (Lee et al., 1992b) are of the diandric type because both initial- and terminal-phase males were present in the investigated populations. However, *Pt. flagellifer* (Lee et al., 1992a) a monandric type because all males in the investigated population were terminal-phase males resulting from sex change from functional females. Based on the gonads and sex distribution according to standard length, *H. poecilopterus*, *H. tenuispinis*, and *Ps. sieboldi* had differentiated testes and ovaries during sex differentiation; some female *H. poecilopterus* and *H. tenuispinis* changed into males after maturation, whereas most female *Ps. sieboldi* became males after maturation. However, *Pt. flagellifer*had differentiated ovaries, and all individuals changed into males after maturation (Fig. 3).

The species-specific sex change of monandric and diandric fish is considered a reproductive strategy for surviving in the marine environment. However, detailed studies are needed to further understand which type is more advantageous in species maintenance, as well as to determine the difference between females that can change sex and females that do not have the genetic capacity to change sex in diandric fish.

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Figure Legends

Fig. 1. Histological observations of gonadal structure in sex-changing wrasse. Ed, efferent duct; Pn, perinucleolar oocyte; Oc, ovarian cavity; Op, ovarian part; Py, primary yolk oocyte; St, seminiferous tubules; Tp, testicular part (Lee et al., 1993).

Fig. 2. Relationship between sex distribution and standard length. A, *Halichoeres poeciopterus* B, *Pteragogus flagellifer* C, *Pseudolabrus sieboldi* D, *Halichoeres tenuispinis* (Lee et al., 1993).

Fig. 3. The sex change pattern of the wrasses inhabiting in the coastal waters of Jeju, Korea

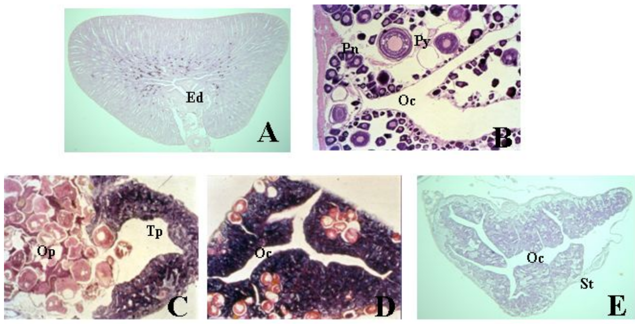

Fig. 1.

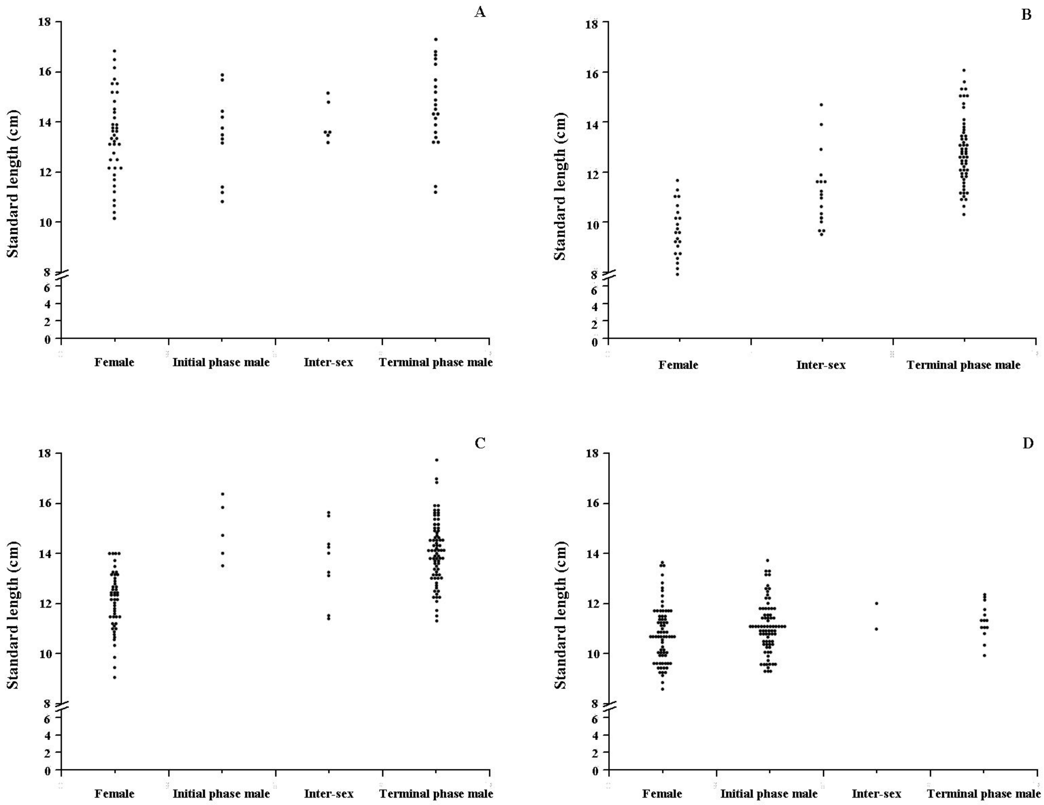
A
B
C
D
Standard length (cm)
18
16
14
12
10
8
6
4
2
0
Female
Initial phase male
Inter-sex
Terminal phase male

Fig. 2.

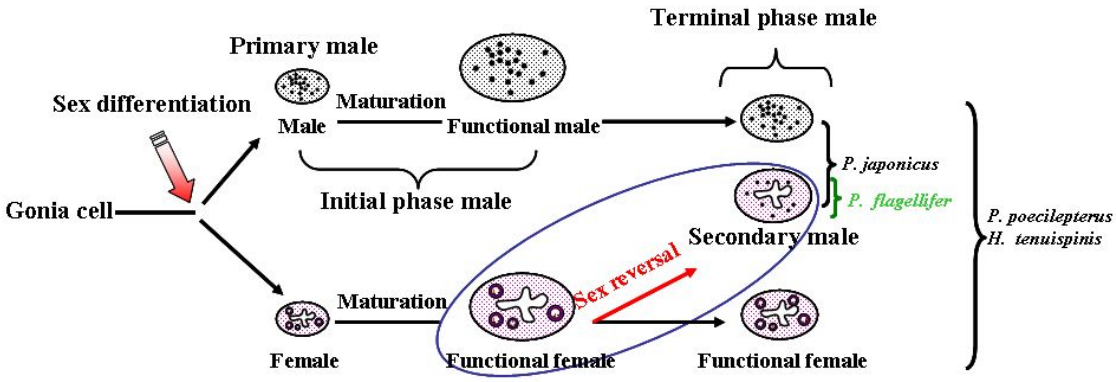
Terminal phase male
Primary male
Sex differentiation
Maturation
Male
Functional male
Initial phase male
Gonia cell
P. japonicus
P. flagellifer
P. poecilepterus
H. tenuispinis
Secondary male
Sex reversal
Maturation
Female
Functional female
Functional female

Fig. 3.