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Chromosomal complements of some Atlantic Blennioidei and Gobioidei species (Perciformes)

Tatiana Barbosa Galvão[1], Luiz Antonio Carlos Bertollo[2], Wagner Franco Molina[1]

1 *Department of Cell Biology and Genetics, Centro de Biociências, Universidade Federal do io Grande do Norte, Campus Universitário, 59078 – 970, Natal, RN, Brazil* **2** *Department of Genetics and Evolution, Universidade Federal de São Carlos, Via Washington Luiz, Km 235, 13565 – 905, São Carlos, São Paulo, Brazil*

Corresponding author: *Wagner Franco Molina* (molinawf@yahoo.com.br)

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Abstract

A remarkable degree of chromosomal conservatism (2n=48, FN=48) has been identified in several families of Perciformes. However, some families exhibit greater karyotypic diversity, although there is still scant information on the Atlantic species. In addition to a review of karyotypic data available for representatives of the suborders Blennioidei and Gobioidei, we have performed chromosomal analyses on Atlantic species of the families Blenniidae, *Ophioblennius trinitatis* Miranda-Ribeiro, 1919 (2n=46; FN=64) and *Scartella cristata* (Linnaeus, 1758) (2n=48; FN=50), Labrisomidae, *Labrisomus nuchipinnis* (Quoy & Gaimard, 1824) (2n=48; FN=50) and Gobiidae, *Bathygobius soporator* (Valenciennes, 1837) (2n=48; FN=56). Besides variations in chromosome number and karyotype formulas, Ag-NOR sites, albeit unique, were located in different positions and/or chromosome pairs for the species analyzed. On the other hand, the heterochromatic pattern was more conservative, distributed predominantly in the centromeric/pericentromeric regions of the four species. Data already available for Gobiidae, Blenniidae and Labrisomidae show greater intra- and interspecific karyotypic diversification when compared to other groups of Perciformes, where higher uniformity is found for various chromosome characteristics. Evolutionary dynamism displayed by these two families is likely associated with population fractionation resulting from unique biological characteristics, such as lower mobility and/or specific environmental requirements.

Keywords

Chromosomal evolution, marine fish, Bleniidae, Gobiidae, Labrisomidae

Introduction

Although karyotypic characteristics for some families of marine fish are already known, information on groups of Perciformes is still significantly disproportionate. Among these, suborders Blennioidei and Gobioidei stand out because of the large number of species they represent.

Suborders Gobioidei, with 2,121 species, and Blennioidei with 732 species, are spread throughout the tropical zone, typically represented by small specimens with low mobility and the ability to withstand changes in temperature and salinity (Nelson 2006).

Species of Blennioidei and Gobioidei investigated (e.g. Cataudela et al. 1973; Garcia et al. 1987; Ene 2003) have shown sufficient chromosomal peculiarities for species discrimination and understanding of their evolutionary aspects. In some families, such as Blenniidae, Labrisomidae and Gobiidae, sharing cryptic morphological characteristics combined with poor knowledge of the biological characteristics for many species, contributes to the relative taxonomic inaccuracy of this group. As such, cytotaxonomic markers (Garcia et al. 1987; Caputo 1998; Caputo et al. 2001) and phylogenetic analyses based on molecular data (Wang et al. 2001; Thacker 2003; Gysels et al. 2004; Almada et al. 2005) have been increasingly used when assessing their kinship relations. Indeed, it has been suggested that phylogenetic analyses combine molecular and morphological data (Thacker 2003), as well as cytogenetic information. However, in light of the diversity in these groups, solid chromosome data are not yet sufficiently available, with only 7.5% of Bleniidae species and 4.5% of Gobioidei was karyotyped (Table 1). Despite the scarcity of data, a high degree of chromosomal polymorphism has been characterized among Gobiidae, primarily Robertsonian rearrangements (Caputo et al. 1999, Ene 2003), along with others such as tandem fusions and pericentric inversions (Giles et al. 1985; Thode et al. 1985; Amores et al. 1990).

The present study focuses on the karyotypic characterization of some Atlantic species of the families Blenniidae, *Ophioblennius trinitatis* Miranda-Ribeiro, 1919 and *Scartella cristata* (Linnaeus, 1758), Labrisomidae, *Labrisomus nuchipinnis* (Quoy & Gaimard, 1824) and Gobiidae, *Bathygobius soporator* (Valenciennes, 1837), through conventional chromosomal analysis, characterization of nucleolar organizer regions (Ag-NORs) and the distribution pattern of C-positive heterochromatin (C-banding) in chromosomes, discussing evolutionary aspects.

Material and methods

A total of 25 specimens of *Ophioblennius trinitatis* (7♂, 4♀ and 14 indeterminate), 11 specimens of *Scartella cristata* (4♂, 5♀ and 2 indeterminate), 13 specimens of *Labrisomus nuchipinnis* (4♂, 4♀ and 5 indeterminate) and 12 specimens of *Bathygobius soporator*, (5♂, 5♀ and 2 indeterminate) were used for chromosome analysis. *Ophioblennius trinitatis* specimens came from the coast of Rio Grande do Norte

Table 1. Cytogenetic data for Blennioidei and Gobioidei (Perciformes).

Suborder/ Family	Species	2n	Karyotype formula	FN	References
Blennioidei					
Blenniidae	*Aidablennius sphynx*	48	4m+4sm+40a	56	Cano et al. (1982)
	A. sphynx	48	2st+46a	50	Cataudella and Civitelli (1975)
	Atrosalarias fuscus	48	48a	48	Arai and Shiotsuki (1973)
	Blennius ocellaris	48	2m+2st+44a	52	Vitturi et al. (1986)
	B. ponticus	48	16sm+10st+22a	74	Garcia et al. (1987)
	B. yatabei	48	6sm+12st+30a	66	Arai and Shiotsuki (1974)
	Coryphoblennius galerita	48	2m+12sm+34a	62	Garcia et al. (1973)
	Dasson trossulus	40	8m+32st/a	48	Arai and Shiotsuki (1974)
	Istiblennius enoshimae	48	2m+46a	50	Arai and Shiotsuki (1973)
	I. lineatus	48	48st/a	48	Arai and Shiotsuki (1974)
	Lipophrys canevai	48	8st+40a	56	Cataudella and Civitelli (1975)
	L. pholis	46	8m+8sm+30a	62	Garcia et al. (1987)
	L. trigloides	46	4m+4sm+10st+28a	64	Cano et al. (1982)
	L. trigloides	48	2m+6sm+18st+22a	74	Cataudella and Civitelli (1975)
	L. trigloides	48	2m+22sm+2st+22a	74	Garcia et al. (1987)
	L. trigloides	48	2m+6sm+18st+22a	74	Vitturi et al. (1986)
	Omobranchus elegans	42	10m+2sm+6st+24a	60	Arai and Shiotsuki (1974)
	O. punctatus	44	4m+40a	48	Arai (1984)
	Ophioblennius trinitatis	46	6m+12st+28a	64	*Present study*
	Parablennius incognitus (=Blennius incognitus)	48	4st+44a	52	Cano et al. (1982)
	P. pilicornis (=Blennius pilicornis)	48	8st+40a	56	Catalano et al. (1985)
	P. gattorugine	48	2m+4sm+42a	54	Vitturi et al. (1986)
	P. pilicornis	48	48a	48	Brum et al. (1992)
	P. sanguinolentus	48	12st+36a	60	Cataudella et al. (1973)
	P. sanguinolentus	48	20sm+10st+18a	78	Garcia et al. (1987)
	P. tentacularis	48	48st/a	48	Vasil'ev (1985)
	P. tentacularis	48	1st+47a	49	Carbone et al. (1987)
	P. tentacularis	47	1sm+46a	48	Carbone et al. (1987)
	Salaria fluviatilis	48	48st/a	48	Cataudella and Civitelli (1975)
	S. pavo	48	8st+40a	56	Cataudella et al. (1973)
	S. pavo	48	16sm+14st+18a	78	Garcia et al. (1987)
	S. pavo	48	2st+46a	50	Vasil'ev (1980)
	Salarias faciatus	48	48a	48	Arai and Shiotsuki (1973)
	S. luctuosus	48	48st/a	48	Arai and Shiotsuki (1974)
	Scartella cristata (=Blennius cristatus)	48	2st+46a	50	Vitturi et al. (1986)
	S. cristata	48	2sm+46st/a	50	Brum et al. (1995)
	S. cristata	48	4st+44a	52	*Present study*
Gobioidei					
Clinidae	*Clinithracus argentatus*	48	2st+46a	50	Vitturi et al. (1986)
Labrisomidae	*Labrisomus nuchipinnis*	48	2sm+46a	50	Affonso (2000)
	L. nuchipinnis	48	2st+46a	50	*Present study*

Suborder/ Family	Species	2n	Karyotype formula	FN	References
Eleotridae	*Dormitator latifrons*	46	44m/sm+2st/a	90	Uribe-Alcocer et al. (1983)
	D. maculatus	46	34m/sm+12st/a	80	Maldonado-Monroy et al. (1985)
	D. maculatus	46	40m/sm+6st/a	86	Molina (2005)
	D. maculatus	46	14m+28sm+2st+2a(♀) 13m+28sm+3st+2a(♂)	90	Oliveira and Almeida-Toledo (2006)
	Eleotrioides strigatus	44	2m+42st/a	46	Arai and Sawada (1974)
	Eleotris acanthopomus	46	46st/a	46	Arai and Sawada (1974)
	E. picta	52	52a	52	Uribe-Alcocer and Diaz-James (1996)
	E. pisonis	46	2m/sm+42st/a	46	Uribe-Alcocer and Diaz-James (1996)
	E. pisonis	46	46a	46	Rocon-Stange (1992)
	E. pisonis	46	46a	46	Molina (2005)
	E. muralis	46	46a	46	Khuda-Bukhsh and Nayak (1990)
	Mogurnda mogurnda	46	6sm+40st/a	52	Arai et al. (1974)
	M. obscura	62	-	-	Nogusa (1960)
	Ophiocara porocephala	48	48a	48	Arai and Fujiki (1979)
	Oxyeleotris marmorata	46	2m+2sm+42a	50	Arai and Fujiki (1979)
Gobiidae	*Aboma latipes*	40	40a	40	Arai and Sawada (1974)
	Acanthogobius flavimanus	44	44st/a	44	Arai and Sawada (1974)
	A. flavimanus	44	36st+8a	80	Arai and Kobayashi (1973)
	A. flavimanus	44	10m/sm/st+34a	54	Arai and Sawada (1975)
	Acentrogobius pflaumi	50	48m/sm+2st/a	98	Nogusa (1960)
	Amblygobius albimaculatus	44	2m+42st/a	46	Nishikawa et al. (1974)
	Aphia minuta	44	44a	44	Caputo et al. (1999)
	A. minuta	43	42a+1st	42	Caputo et al. (1999)
	A. minuta	42	1m+1st+40a	44	Caputo et al. (1999)
	A. minuta	42	1M+1m+40a	44	Caputo et al. (1999)
	A. minuta	41	2M+1st+38a	44	Caputo et al. (1999)
	Apocryptes bato	46	24m+10sm+12a	80	Nayak and Khuda-Bukhsh (1987)
	A. lanceolatus	38	14m+22sm+2st	76	Nayak and Khuda-Bukhsh (1987)
	Awaous grammepomus	46	46st/a	46	Khuda-Bukhsh and Barat (1987)
	A. tajasica	46	46a	46	Stange and Passamani (1986)
	Bathygobius fuscus	48	48a	48	Arai and Sawada (1975)
	B. soporator	48	2m+46a	50	Brum et al. (1996)
	B. soporator	48	2m/sm+46a	50	Cipriano et al. (2002)
	B. soporator	48	2m+6st+40a	56	*Present study*
	B. stellatus	46	2st+44a	48	Vasil'ev (1985)
	B. stellatus	47	1sm+2st+43a	49	Vasil'ev (1985)
	Boleophthalmus boddaerty	46	46m/sm	92	Subrahmanyan (1969)
	B. glaucus	46	12m+20sm+2st+12a	80	Manna and Prasad (1974)
	B. pectinirostrus	46	46st/a	46	Arai and Sawada (1975)
	Bostrichthys sinensis	48	4m/sm+44a	52	Arai et al. (1974)
	Chaenogobius annularis	44	18sm+26st/a	62	Arai and Sawada (1975)
	C. annularis	44	36m/sm+8a	80	Arai et al. (1974)
	C. annularis	44	44a	44	Nogusa (1960)
	C. castaneus	44	36m/sm/st+8a	80	Nishikawa et al. (1974)
	C. isaza	44	12sm+32st/a	56	Arai and Sawada (1975)
	C. urotaenia	44	-	-	Nogusa (1960)

Suborder/ Family	Species	2n	Karyotype formula	FN	References
	C. urotaenia	42	14sm+28a	56	Yamada (1967)
	Chasmichthys dolichognatus	44	44st/a	44	Arai and Sawada (1975)
	C. gulosus	44	44st/a	44	Arai and Sawada (1975)
	C. gulosus	44	16m/sm/st+28a	60	Nishikawa et al. (1974)
	Ctenogobius criniger	50	34m/sm+6st+10a	90	Arai and Sawada (1974)
	Gillichthys mirabilis	44	12sm+32a	56	Chen and Ebeling (1971)
	G. seta	44	6m+14sm+24a	64	Chen and Ebeling (1971)
	Glossogobius fasciatopunctatus	44	10m+28sm+2st+4a	84	Fei and Tao (1987)
	G. giuris	46	46a	46	Rishi and Singh (1982)
	Gobiodon citrinus	44	2m+42st/a	46	Arai and Sawada (1974)
	G. citrinus	43	1m+42st/a	44	Arai and Sawada (1974)
	G.quinquestrigatus	44	44a	44	Arai and Fujiki (1979)
	G. rivulatus	44	44a	44	Arai and Fujiki (1979)
	Gobioides rubicundus	46	2m+26sm+10st+8a	84	Manna and Prasad (1974)
	Gobionellus shufeldti	48	48a (♀)	48	Pezold (1984)
	G. shufeldti	47	46a+1m (♂)	48	Pezold (1984)
	Gobiosoma macrodon	38	38a	38	Musammil (1974)
	G. zebrella	38	38a	38	Musammil (1974)
	Gobius abei	46	-	-	Nogusa (1960)
	G. bucchichi	44	2sm+42a	46	Thode and Alvarez (1983)
	G. cobitis	46	46a	46	Caputo et al. (1997)
	G. cruentatus	46	2st+44a	48	Thode and Alvarez (1983)
	G. fallax	38	8m/sm+30a	46	Thode et al. (1988)
	G. fallax	39	7m/sm+32a	46	Thode et al. (1988)
	G. fallax	40	6m/sm+34a	46	Thode et al. (1988)
	G. fallax	40	7m/sm+33a	47	Thode et al. (1988)
	G. fallax	41	5m/sm+36a	46	Thode et al. (1988)
	G. fallax	42	4m/sm+38a	46	Thode et al. (1988)
	G. fallax	43	3m/sm+40a	46	Thode et al. (1988)
	G. niger	52	2m+4sm+16st+30a	74	Vitturi and Catalano (1989)
	G. niger	51	3m+4sm+16st+28a	74	Caputo et al. (1997)
	G. niger	50	4m+4sm+16st+26a	74	Caputo et al. (1997)
	G. niger	49	5m+4sm+16st+24a	74	Caputo et al. (1997)
	G. paganellus	48	2sm+46a	50	Caputo et al. (1997)
	G. similis	44	?		Nogusa (1960)
	Gobiusculus flavescens	46	6m/sm+40a	52	Klinkhardt (1992)
	Luciogobius grandis	44	?		Arai (1981)
	L. guttatus	44	?		Arai and Kobayashi (1973)
	Mesogobius batrachocephalus	30	16m+14a	46	Ivanov (1975)
	Neogobius cephalarges	46	46a	46	Vasil'ev (1985)
	N. constructor	42	4m/sm+38a	46	Vasil'ev and Vasil'yeva (1994)
	N. cyrius	36	structural polymorphism		Vasil'ev and Vasil'yeva (1994)
	N. fluviatilis	46	46a	46	Vasil'ev (1985)
	N. eurycephalus	32	12m+2sm+18a	46	Ene (2003)

Suborder/ Family	Species	2n	Karyotype formula	FN	References
	N. eurycephalus	31	13m+2sm+16a	46	Ene (2003)
	N. eurycephalus	30	14m+2sm+14a	46	Ene (2003)
	N. gymnotrachelus	46	46a	46	Vasil'ev and Grigoryan (1992)
	N. kessleri	46	46a	46	Vasil'ev (1985)
	N. melanostomus	46	46a	46	Vasil'ev (1985)
	N. rhodionovi	46	46a	46	Vasil'ev and Vasil'yeva (1994)
	Odontamblyops rubicundus	46	4m+16sm+26st/a	66	Arai and Sawada (1975)
	Padogobius martensi	46	1m+3sm+2st+40a	52	Cataudella et al. (1973)
	Parioglossus raoi	46	46st/a	46	Webb (1986)
	Periophthalmus cantonensis	46	18m+12sm+16st/a	76	Arai and Sawada (1975)
	Pomatoschistus lozanoi	37	3m+12sm+10st+12a	62	Webb (1980)
	P. microps	46	4m+16sm+20st+6a	86	Klinkhardt (1989)
	P. minutus	46	4m+16sm+16st+10a	82	Klinkhardt (1989)
	P. minutus	46	18sm+18st+10a	82	Klinkhardt (1992)
	P. norvegicus	32	10m+10sm+8st+4a	60	Webb (1980)
	P. pictus	46	22m/sm+12st+12a	80	Klinkhardt (1992)
	Proterorhinus marmoratus	46	46a	46	Rab (1985)
	Pterogobius elapoides	44	14sm+30st	88	Arai and Kobayashi (1973)
	P. zonoleucus	44	14sm+30st	88	Arai and Sawada (1975)
	Quietula guaymasiae	42	6m+4sm+32a	52	Cook (1978)
	Q. y-cauda	42	42a	42	Cook (1978)
	Rhinogobius brunneus	44	44a	44	Nishikawa et al. (1974)
	R. flumineus	44	44a	44	Arai and Kobayashi (1973)
	R. giurinus	44	44a	44	Nishikawa et al. (1974)
	Rhodoniichthys laevis	42	16m/sm+26st	84	Arai et al. (1974)
	Sicyopterus japonicus	44	10m+10sm+24a	64	Arai and Fujiki (1979)
	Synechogobius hasta	44	2m+42st/a	46	Arai and Sawada (1975)
	Tridentiger obscurus	44	10m/sm+34a	54	Arai et al. (1974)
	T. trigonocephalus	44	28m/sm/st+16a	72	Arai et al. (1973)
	T. trigonocephalus	46	16sm+6st+24a	68	Fei and Tao (1987)
	Trypauchen vagina	46	12m+6sm+10st+18a	74	Khuda-Bukhsh (1978)
	Tukugobius flumineus	44	44a	44	Nadamitsu (1974)
	Zosterisessor ophiocephalus (= *Gobius ophiocephalus*)	46	46a	46	Vasil'ev (1985)
	Zosterisessor ophiocephalus (= *Gobius ophiocephalus*)	45	1st+45a	47	Vasil'ev (1985)
	Zosterisessor ophiocephalus	46	2m/sm+44a	48	Caputo et al. (1996)

(5°13'1.73"S; 35°9'57.85"W), northeastern Brazil (n=1), and the Saint Peter and Saint Paul (n=8) (00°55'02"N; 29°20'42"W) and Fernando de Noronha (n=16) (3°52'11"S; 32°26'13"W) archipelagos. The remaining specimens were collected on the coast of Rio Grande do Norte. Individuals were previously submitted to mitotic stimulation with compound attenuated antigens, for 24 to 48 hours (Molina 2001, Molina et al. 2010), anesthetized with clove oil (Eugenol) and sacrificed for the removal of anterior kidney fragments. Sexing of specimens was performed by macroscopic and microscopic examination of the gonads. Chromosome preparations were obtained from kidney

cells (Gold et al. 1990). Nucleolar organizer regions (NORs) were identified by stain with silver nitrate - Ag-NORs (Howell and Black 1980) and C-positive heterochromatin sites through C-banding (Sumner 1972).

Metaphase preparations were examined and photographed on an Olympus BX50 photomicroscope, using an Olympus DP70 digital camera system. Chromosomes were classified according to the position of the centromere in metacentrics (m), submetacentrics (sm), subtelocentrics (st) and acrocentrics (a) (Levan et al. 1964) and organized in order of decreasing size. The chromosome formula and FN (fundamental number or number of chromosomal arms) were established for each species, considering acrocentric chromosomes with a single arm and the remaining chromosomes exhibiting two arms.

Results

Cytogenetic analyses of Blenniidae species (Blennioidei)

Ophioblennius trinitatis showed 2n=46, with a chromosome formula equal to 6m+12st+28a (FN=64), irrespective of sex. Although chromosomes showed a gradual decline in size, the smallest acrocentric pairs corresponded to approximately one-third of the largest metacentric pairs. Nucleolar organizer regions are located in the terminal portions of the short arm on pair 9, the smallest subtelocentric pair. C-positive heterochromatin is discretely located in the centromeric/pericentromeric region of the chromosomes (Fig. 1a, b).

Scartella cristata showed 2n=48 chromosomes, with a chromosome formula equal to 4st+44a (FN=52). The karyotype also displays a gradual reduction in chromosome size. However, the largest chromosome pair exhibits only double the size in relation to the smallest karyotype pair. Ribosomal sites are located on the terminal portions of the short arms on chromosome pair 1. C-positive heterochromatin is also reduced and located in the centromeric regions of chromosomes (Fig. 1c, d).

Cytogenetic analyses of Labrisomidae and Gobiidae species (Gobioidei)

Labrisomus nuchipinnis (Labrisomidae) showed 2n=48 chromosomes with a chromosome formula of 2st+46a (FN=50), showing relatively more differentiated size between the largest and smallest chromosomes of the karyotype. Nucleolar organizer regions are in the terminal portions of the long arms on pair 2, corresponding to the largest pair of acrocentric chromosomes. C-positive heterochromatin was showed in the centromeric/pericentromeric region of all chromosome pairs, in relatively conspicuous blocks (Fig. 1e, f).

Bathygobius soporator (Gobiidae) also displayed the karyotype composed of 2n=48 chromosomes, but with the chromosome formula distinct from that of *L. nuchipinnis,* specifically, 2m+6st+40a (FN=56). Size difference between the largest and smallest

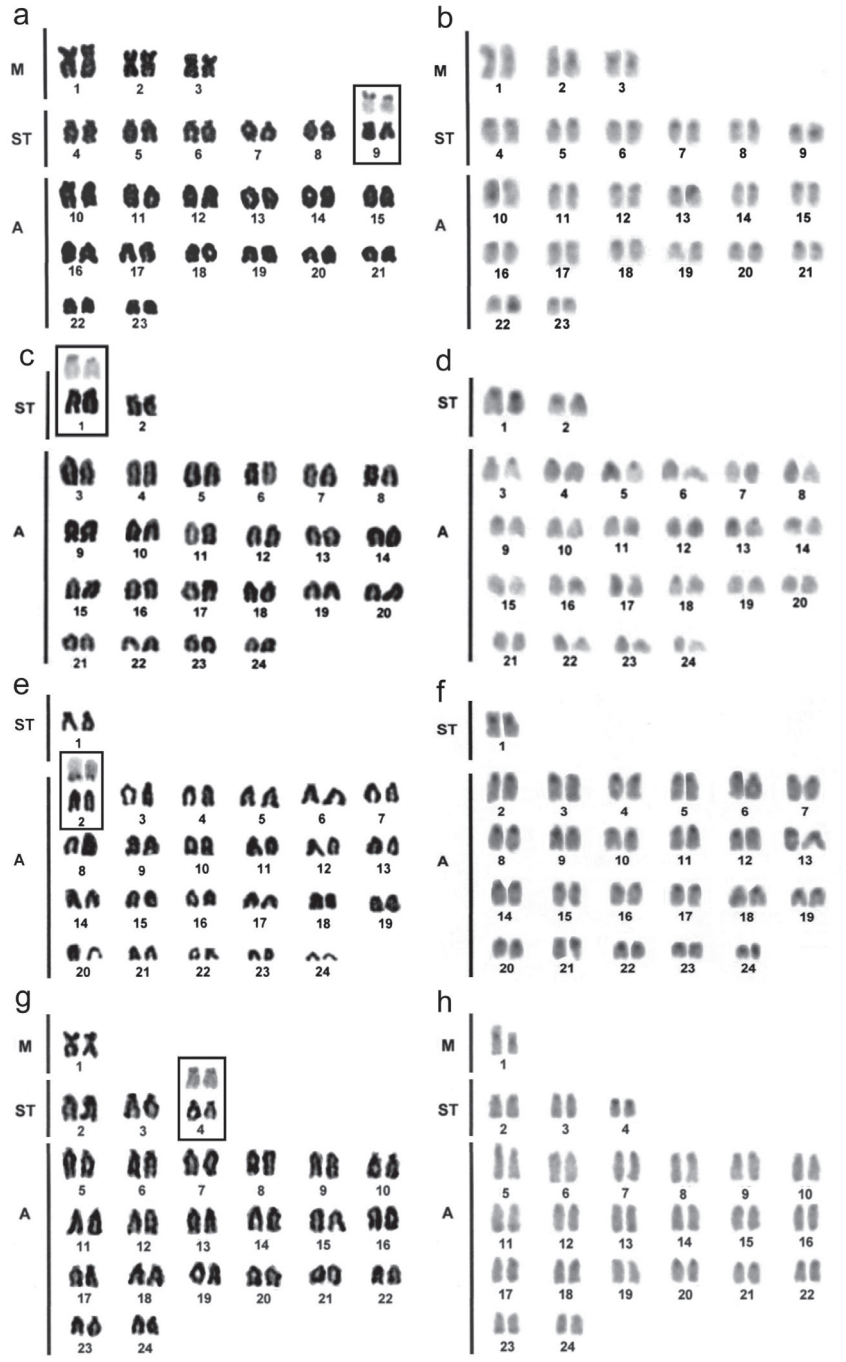

Figure 1. Karyotypes under Giemsa staining **a, c, e, g** and C-banding **b, d, f, h** of *Ophioblenius trinitatis;* **a, b** *Scartella cristata;* **c, d** *Labrisomus nuchipinnis;* **e, f** and *Bathygobius soporator;* **g, h** Ag-NOR-bearing chromosome pairs are highlighted.

chromosomes of the karyotype was far less pronounced. Ribosomal sites were on the terminal portions of the short arms on chromosome pair 4. C-banding showed discrete heterochromatic regions in the centromeric regions of most chromosomes and telomeric regions of some acrocentric pairs (Fig. 1g, h).

Discussion

Though many perciform families display a conserved karyotype pattern, with 2n=48 acrocentric chromosomes, some groups demonstrate dynamic tendencies in relation to chromosome evolution (Molina 2007). Much of identifiable chromosome diversity is attributed to pericentric inversions, the most common mechanism of chromosome evolution in this order (Galetti et al. 2000, 2006).

Representatives of the suborder Blennioidei (e.g., Carbone et al. 1987) and Gobioidei (e.g., Arai and Sawada 1974, 1975; Thode et al. 1988; Oliveira and Almeida-Toledo 2006) stand out for their greater karyotype variability and diversity. This includes species with conserved karyotyes and those that are highly diversified.

Within the Blennioidei, the Blenniidae, a monophyletic family, is divided into six tribes including Salariini and Parablenniini which, in turn, include the Atlantic species *O. trinitatis* and *S. cristata* respectively (Nelson 2006). Comparisons of mitochondrial DNA sequences in samples of *Ophioblennius* Gill, 1860 collected throughout the Atlantic suggest that the genus consists of six distinct lineages. One of these corresponds to species found in the Pacific, while the rest are recorded in the biogeographic provinces of the Atlantic: Brazilian, Caribbean, Mid-Atlantic, Sao Tome and Azores/Cape Verde (Muss et al. 2001). Chromosome characteristics reported here for *O. trinitatis* are the first for the genus, exhibiting 2n=46, 6m+12st+28a and FN=64. The relatively low diploid number and higher fundamental number in relation to the mean of other species of Blenniidae (Table 1), as well as the presence of large metacentric chromosomes, suggests pericentric inversion events and the occurrence of Robertsonian translocation involving two of its chromosome pairs. In turn, *S. cristata*, while also belonging to the family Blenniidae, has a distinct karyotype of 2n=48, 4st+44a and FN=52. Thus, *S. cristata* differs from *O. trinitatis* in that it contains an extra pair of chromosomes, lacks metacentric chromosomes and has different numbers of subtelocentric and acrocentric chromosomes in the karyotype. The karyotype of the *S. cristata* population studied here differs from the karyotypes previously described for the coastal population of Rio de Janeiro (SE Brazil), with 2sm+46st/a (Brum et al. 1994), and the Mediterranean population, with 2st+46a (Vitturi et al. 1986). Nevertheless, despite the growing number of discordant karyotype descriptions between populations on the NE and SE coasts of Brazil, one cannot rule out that these differences may arise from the difficulty in precisely defining types of cryptic chromosomes in the karyotype of this species.

In spite of displaying relative diversity in chromosome structure, only 18.5% of Blennioidei species exhibit differences in the basal diploid number, 2n=48 chromosomes. As shown in table 1, diploid numbers for representatives of this suborder vary

between 2n=40, found in *Dasson trossulus* (Jordan & Snyder, 1902) (Arai and Shiotsuki 1974) and 2n=52 in *Gobius niger* Linnaeus, 1758 (Vitturi and Catalano 1989), but with a conspicuous modal value of 2n=48.

In contrast to Blennioidei, suborder Gobioidei shows much more dynamic karyotype evolution, demonstrating highly variable karyotype patterns, where the diploid number ranges from 2n=30 for *Neogobius eurycephalus* (Kessler, 1874) (Ene 2003), to 2n=62 in *Mogurnda mogurnda* (Richardson, 1844) (Nogusa 1960). Cytogenetic data for 95 species show that only 9.6% have 2n=48 chromosomes, whereas the highest frequencies observed correspond to 2n=46 in 40% of species investigated, and 2n=44 in 32% (Table 1). As such, both Gobioidei species studied here are included in the group showing 2n=48 chromosomes, *L. nuchipinnis* with 2st+46a and FN=50 and *B. soporator* with 2m+6st+40a and FN=56. Thus, *B. soporator* differs from *L. nuchipinnis* in the presence of metacentric chromosomes and different numbers of subtelocentric and acrocentric chromosomes in the karyotype.

Among chromosome rearrangements involved in karyotypic differentiation of Gobiidae, Robertsonian fusions stand out, and are likely the most common event in this group (Amores et al. 1990; Galetti et al. 2000). However, other more complex changes in karyotypic structure (Thode et al. 1988; Vitturi and Catalano 1989; Caputo et al. 1997; Caputo et al. 1999), as well as the presence of different sex chromosomes (e.g., Pezold 1984; Baroiller et al. 1999), can also be observed, corroborating the high dynamic evolution that characterizes suborder Gobioidei. It has been suggested that the baseline/ancestral karyotype for Gobiidae would consist of 2n=46 acrocentric chromosomes (Vasil'ev and Grigoryan 1993), from which an increase in bi-brachial chromosomes would characterize more derived karyotypes. Based on this proposal, *B. soporator* (FN=56) would experience a greater number of structural rearrangements during its karyotypic evolution process in relation to *L. nuchipinnis* (FN=50).

Location and frequency of Ag-NOR sites are efficient cytotaxonomic markers in many groups of fish (Caputo 1998). Among species of Gobiidae, at least six different arrangement patterns for nucleolar organizer regions have been identified (Fig. 2), which supports the occurrence of intense karyotypic diversification mechanisms in this group. Thus, Ag-NOR sites can be found (a) in the telomeric region on the short arm of a single pair of acrocentric chromosomes, as in *Gobius fallax* Sarato, 1889 (Thode et al. 1983) and *Gobius paganellus* Linnaeus, 1758 (Caputo 1998); (b) in the telomeric region on the long arm of a single pair of acrocentrics, such as in *Zosterisessor ophiocephalus* (Pallas, 1814) (Caputo 1998); (c) in the interstitial/pericentromeric region on the long arm of a single pair of acrocentric chromosomes, as seen in *Proterorhinus marmoratus* (Pallas, 1814) (Ráb 1985) and *Gobius cobitis* Pallas, 1814 (Caputo 1998); (d) in the telomeric region on the short arm of a single subtelocentric pair, described in *B. soporator*; (e) in the interstitial/pericentromeric region on the long arm of a single metacentric pair, observed in *N. eurycephalus* (Ene 2003); and (f) in the telomeric regions on the short arms of two acrocentric chromosome pairs, recorded in *Gobiusculus flavescens* (Fabricius, 1779) (Klinkhardt 1992).

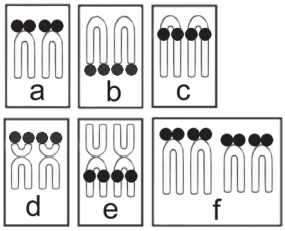

Figure 2. Ag-NOR phenotypes **a–f** described in species of Gobiidae. Ag-NORs sites described in the karyotypes of Gobiidae species were found **a** in the telomeric region on the short arm of a single pair of acrocentric chromosomes **b** in the telomeric region on the long arm of a single pair of acrocentrics **c** in the interstitial/pericentromeric region on the long arm of a single pair of acrocentric chromosomes **d** in the telomeric region on the short arm of a single subtelocentric pair **e** in the interstitial/pericentromeric region on the long arm of a single metacentric pair and **f** in the telomeric regions on the short arms of two acrocentric chromosome pairs.

Few data are available on ribosomal sites for Labrisomidae. Ag-NORs in *L. nuchipinnis* exhibit the phenotype (b) described above, in addition to both species of Blenniidae, *O. trinitatis* and *S. cristata*, which may suggest an ancestral condition for this location.

In contrast, other chromosome characteristics, such as C-positive heterochromatin distribution, may be more conserved. This occurs in several species of Percifomes where discrete blocks are preferentially located in the centromeric/pericentromeric regions of chromosomes (Molina 2007). This pattern is repeated in *S. cristata*, *O. trinitatis* and *L. nuchipinnis*, as well as in some Gobiidae, such as *G. cobitis, Z. ophiocephalus* and *N. eurycephalus* (e.g. Caputo et al. 1997; Ene 2003). In *B. soporator*, in addition to centromeric/pericentromeric regions, heterochromatic sites are also observed in terminal regions of some chromosomes. This arrangement has already been described for other Gobiidae, including *G. paganellus* and *G. niger*, where pericentromeric and telomeric heterochromatic regions are distributed among almost all chromosomes (Amores et al. 1990; Caputo et al. 1997).

Moreover, karyotypic diversity present in Gobioidei is increased by the occurrence of chromosome polymorphisms frequently observed in this group. This is particularly evident in several examples of intraspecific karyotypic variability, as well as polymorphisms involving different types of chromosome rearrangements, such as in *G. niger* (Vitturi and Catalano 1989; Caputo et al. 1997) and *G. fallax* (Thode et al. 1988). Data obtained for the paedomorphic Gobiidae *Aphia minuta* (Risso, 1810) also show variations in the diploid number and chromosome formula, resulting in five different cytotypes (2n=41–44 and FN=42-44) (Caputo et al. 1999). Similar karyotypic variability was reported in *N. eurycephalus,* where three specific cytotypes (2n=30, 31 and 32) were associated to the occurrence of centric fusions (Ene 2003). All these examples demonstrate clear chromosomal dynamism, with possible transitions to new karyotype patterns.

In fact, karyotypic diversity among Blennioidei and Gobioidei seems to accompany phyletic diversification of these groups. This is a result of vicariant factors (Pampoulie et al. 2004) and could be favored by their low dispersive potential (Fanta 1997), as well as ecological specificities that favor population fractionation in this family (Huyse et al. 2004). The present study also highlight the importance of ribosomal sites as effective chromosomal markers in the further cytogenetic studies in gobiids species.

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References

Affonso PRAM (2000) Caracterização citogenética de peixes de recifes de corais da família Pomacanthidae (Perciformes). Master thesis, Universidade Federal de São Carlos, São Carlos, SP, Brasil. [in Portuguese]

Affonso PRAM, Guedes W, Pauls E, Galetti Jr PM (2001) Cytogenetic analysis of coral reef fishes from Brazil (families Pomacanthidae and Chaetodontidae). Cytologia 66: 379–384.

Akihito, Iwata A, Kobayashi T, Ikeo K, Imanishi T, Ono H, Umehara Y, Hamamatsu C, Sugiyama K, Ikeda Y, Sakamoto K, Fumihito A, Ohno S, Gojobori T (2000) Evolutionary aspects of gobioid fishes based upon a phylogenetic analysis of mitochondrial cytochrome *b* genes. Gene 259: 5–15.

Almada F, Almada VC, Guillemaud T, Wirtz P (2005) Phylogenetic relationships of the northeastern Atlantic and Mediterranean blenniids. Biological Journal of the Linnean Society 86: 283–295.

Amores A, Giles V, Thode G, Alvarez MC (1990) Adaptive charater of a Robertsonian fusion in chromosomes of the fish *Gobius paganellus* (Pisces, Perciformes). Heredity 65: 151–155.

Arai R (1981) Fishes of the genus *Luciogobius* and *Inu* (Gobiidae) from peninsula Idzu, Central Japan. Memoirs of National Science Museum 14: 151–166.

Arai R (1984) Karyotypes of a mugiloidid, *Parapercis kamoharai*, and a blenniid, *Omobranchus punctatus* (Pisces, Perciformes). Bulletin of National Science Museum 10: 209–213.

Arai R, Fujiki S (1979) Chromosomes of Japanese gobioid fishes (IV). Bulletin of National Science Museum 5: 153–159.

Arai R, Katsuyama I, Sawada Y (1974) Chromosomes of Japanese gobioid fishes (II). Bulletin of National Science Museum 17: 269–279.

Arai R, Kobayasi H (1973) A chromosome study on thirteen species of Japanese gobiid fishes. Jap. J. Ichthyol. 20: 1–6.

Arai R, Sawada Y (1974) Chromosomes of Japanese gobioid fishes (II). Bulletin of National Science Museum 17: 97–102.

Arai R, Sawada Y (1975) Chromosomes of Japanese gobioid fishes (III). Bulletin of National Science Museum 1: 225–232.

Arai R, Shiotsuki K (1973) A chromosome study on three species of the tribe Salariini from Japan (Pisces, Blenniidae). Bulletin of National Science Museum 16: 581–584.

Arai R, Shiotsuki K (1974) Chromosomes of six species of Japanese blennioid fishes Bulletin of National Science Museum 17: 261–268.

Brum MJI, Aguilar CT, Correa MM, Oliveira C, Galetti Jr PM (1992) Estudos citogenéticos em peixes marinhos, análises cromossômicas nas famílias Clupeidae (Clupeiformes), Serranidae, Pomadasyidae and Blenniidae. Proceedings of the IV. Simpósio de Citogenética Evolutiva e Aplicada de Peixes Neotropicais, Rio de Janeiro, 1992, Rio de Janeiro, 43.

Brum MJI, Galetti Jr PM (1997) Teleostei ground plan karyotype. Journal of Computational Biology 2: 91–102.

Brum MJI, Oliveira C, Correa MM, Oliveira CC, Galetti Jr PM (1995) Cytogenetic studies on the Perciformes *Orthopristis ruber* (Haemulidae) and *Scartella cristata* (Blenniidae). Caryologia 48: 309–318.

Cano J, Alvarez MC, Thode G, Munoz E (1982) Phylogenetic interpretation of chromosomal and nuclear-DNA-content data in the genus *Blennius* (Blenniidae: Perciformes). Genetica 58: 11–16.

Caputo V (1998) Nucleolar organizer (NOR) and cytotaxonomic implications in six species of gobiid fishes (Perciformes, Gobiidae). Italian Journal of Zoology 65: 93–99.

Caputo V, Caniglia ML, Machella N (1999) The chromosomal complement of *Aphia minuta*, a paedomorphic goby. Journal of Fish Biology 55: 455–458.

Caputo V, Machella N, Cerioni-Nisi P, Olmo E (2001) Cytogenetics of nine species of Mediterranean blennies and additional evidence for an unusual multiple sex-chromosome system in *Parablennius tentacularis* (Perciformes, Blenniidae). Chromosome Research 9: 3–12.

Caputo V, Marchegiani F, Sorice M, Olmo E (1997) Heterochromatin heterogeneity and chromosome variability in four species of gobiid fishes (Perciformes: Gobiidae). Cytogenetics and Cell Genetics 79: 266–271. doi: 10.1159/000134739

Caputo V, Vitturi R, Odierna G, Cano J, Olmo E, Colomba MS (1996) Characterization of mitotic chromosomes in the gobiid fish *Zosterisessor ophiocephalus* (Pallas, 1811) (Perciformes, Gobiidae). Biologisches Zentralblatt 115: 328–336.

Carbone P, Vitturi R, Catalano E, Macaluso M (1987) Chromosome sex determination and Y-autosom fusion in *Blennius tentacularis* (Brunnich, 1765) (Pisces, Blenniidae). Journal of Fish Biology 31: 597–602. doi: 10.1111/j.1095-8649.1987.tb05264.x

Catalano E, Vitturi R, Zava B, Macaluso M (1985) Ritrovamento di *Parablennius pilicornis* (Cuvier, 1829) nelle acque italiane e suo cariotipo (Pisces, Blenniidae). Atti della Societa Italiana di Scienze Naturali e del Museo Civico di Storia Naturale di Milano 126: 155–164.

Cataudella S, Civitelli MV (1975) Cytotaxonomical consideration of the genus *Blennius* (Pisces: Perciformes). Experientia 31: 167–169.

Cataudella S, Civitelli MV, Capanna E (1973) The chromosomes of some mediterranean teleosts: Scorpaenidae, Serranidae, Labridae, Blenniidae, Gobiidae (Pisces: Scorpaeniformes, Perciformes). Bolletino di Zoologia 40: 385–389.

Chen TR, Ebeling AW (1971) Chromosomes of the goby fishes in the genus *Gillichthys*. Copeia 1971: 171–174.

Cook PC (1978) Karyotypic analysis of the gobiid fish genus *Quietula* Jordan and Evermann. Journal of Fish Biology 12: 173–179.

Ene AC (2003) Chromosomal polymorphism in the goby *Neogobius eurycephalus* (Perciformes: Gobiidae). Marine Biology 142: 583–588. doi: 10.1007/s00227-002-0978-3

Fanta E (1997) Behaviour and circadian rhythm of the fish *Bathygobius soporator* Valenciennes (Gobiidae) under the influence of environmental salinity and temperature. Revista Brasileira de Zoologia 14: 221–224.

Fei Z, Tao R (1987) Studies on the karyotypes of four species in Gobioidei and compared with other fishes in there. Journal of Zhejiang College of Fisheries 6: 127–131.

Floeter SR, Gasparini JL (2000) The southwestern Atlantic reef fish fauna: composition and zoogeographic patterns. Journal of Fish Biology 56: 1099–1114. doi: 10.1111/j.1095-8649.2000.tb02126.x

Garcia E, Alvarez MC, Thode G (1987) Chromosome relationships in the genus *Blennius* (Blenniidae, Perciformes) C-banding patterns suggest two karyoevolutional pathways. Genetica 72: 27–36.

Galetti Jr PM, Aguilar CT, Molina WF (2000) An overview on marine fish cytogenetics. Hydrobiologia 420: 55–62.

Galetti Jr PM, Molina WF, Affonso PRAM, Aguilar CT (2006) Assessing genetic diversity of Brazilian reef fishes by chromosomal and DNA markers. Genetica 126: 161–177.

Giles V, Thode G, Alvarez MC (1985) A new Robertsonian fusion in the multiple chromosome polymorphism of a Mediterranean population of *Gobius paganellus* (Gobiidae, Perciformes). Heredity 55: 255–260.

Gold JR, Li C, Shipley NS, Powers PK (1990) Improved methods for working with fish chromosomes with a review of metaphase chromosome banding. Journal of Fish Biology 37: 563–575.

Gysels ES, Hellemans B, Pampoulie C, Volckaert AM (2004) Phylogeography of the common goby, *Pomatoschistus microps,* with particular emphasis on the colonization of the Mediterranean and the North Sea. Molecular Ecology 33: 403–417.

Howell WM, Black DA (1980) Controlled silver staining of nucleolus organizer region with protective colloidal developer: a 1-step method. Experientia 36: 1014–1015.

Huyse T, Houdt JV, Volckaert FA (2004) Paleoclimatic history and vicariant speciation in the "sand goby" group (Gobiidae, Teleostei). Molecular Phylogenetics and Evolution 32: 324–36.

Ivanov VN (1975) Chromosomes of the Black sea Gobiidae - *Gobius melanostomus* (Pallas) and *Gobius batrachocephalus* (Pallas). Tsitologiya i Genetika 9: 551–552.

Khuda-Bukhsh AR (1978) Somatic chromosomes of an estuarine fish, *Trypauchen vagina* (Fam.: Gobiidae) from Sagar Island, West Bengal, India. Current Science 47: 137–138.

Khuda-Bukhsh AR, Barat A (1987) Chromosomes in fifteen species of Indian teleost (Pisces). Caryologia 40: 131–144.

Khuda-Bukhsh AR, Nayak K (1990) Karyotypic studies in six species of brackish water fishes from India. Kromosomo 2: 1955–1960.

Klinkhardt MB (1989) Untersuchungen zur Karyologie und Fruchtbarkeit von *Pomatoschistus microps* (Kroyer) und *P. minutus* (Pallas) (Teleostei, Gobiidae). Aus einem inneren Küstengewässer der südwestlichen Ostsee. Zoologischer Anzeiger 222: 177–190.

Klinkhardt MB (1992) Chromosome structures of four Norwegian gobies (Gobiidae, Teleostei) and a hypothetical model of their karyo-evolution. Chromatin 3: 169–183.

Levan A, Fredga K, Sandberg AA (1964) Nomenclature for centromeric position on chromosomes. Hereditas 52: 201–220.

Maldonado-Monroy MC, Uribe-Alcocer M, Arreguin Spinoza J, Castro Perez A (1985) Karyotypical studies on *Dormitator maculatus* Bloch and *Gobiomorus maculatus* Lacepede (Gobiidae, Perciformes). Cytologia 50: 15–21.

Manna GK, Prasad R (1974) Chromosome analysis in three species of fishes belonging to family Gobiidae. Cytologia 39: 609–618.

Molina WF (2005) Intraspecific karyotypical diversity in brackish water fishes of the Eleotridae family (Pisces, Perciformes). Cytologia 70: 39–45.

Molina WF, Galetti Jr PM (2004) Karyotypic changes associated to the dispersive potential on Pomacentridae (Pisce, Perciformes). Journal of Experimental Marine Biology and Ecology 309: 109–119. doi: 10.1016/j.jembe.2004.03.011

Musammil A (1974) A chromosome study of two species of *Gobiosoma* from Venezuela (Gobiidae, Teleostei). Boletim del Instituto Oceanografico da Universidad do Oriente 13: 11-16.

Muss A, Robertson DR, Stepien CA, Wirtz P, Bowen BW (2001) Phylogeography of Ophioblennius: The role of ocean currents and geography in reef fish evolution. Evolution 55: 561–572. doi: 10.1111/j.0014-3820.2001.tb00789.x

Nadamitsu S (1974) Karyological studies of two types of Gobioid fish, "Yoshinobori". Bulletin of Hiroshima Women's University 9: 3–9.

Nayak K, Khuda-Bukhsh AR (1987) Chromosomes of two species of fishes *Apocryptes* (Gobiidae: Pisces). Environment and Ecology 5: 371–373.

Nelson JS (2006) Fishes of the world, 4 ed, New York, 601 pp.

Nishikawa S, Amaoka K, Nakanishi K (1974) A comparative study of chromosomes of twelve species of gobioid fish in Japan. Japanese Journal of Ichthyology 21: 61–71.

Nogusa S (1960) A comparative study of the chromosomes of fishes with particular considerations on taxonomy and evolution. Memoirs of the Hyogo University of Agriculture 3: 1–62.

Oliveira C, Almeida-Toledo LF (2006) Evidence of an XX/XY sex chromosome system in the fish *Dormitator maculatus* (Teleostei, Eleotrididae). Genetics and Molecular Biology 29(4): 653–655.

Pampoulie C, Gysels ES, Maes GE, Hellemans B, Lentjes V, Jones AG, Volckaert FAM (2004) Evidence for fine-scale genetic structure and estuarine colonization in a potential high gene flow marine goby (*Pomatoschistus minutus*). Heredity 92: 434–445.

Pezold F (1984) Evidence for multiple sex chromosomes in the freshwater goby, *Gobionellus shufeldti* (Pisces: Gobiidae). Copeia 1984: 235–238.

Rab P (1985) Karyotype of the Danube goby, *Proterorhinus marmoratus* (Pisces, Gobiidae). Folia Zoologica (Brno) 34: 329–334.

Rishi KK, Singh J (1982) Karyological studies on five estuarine fishes. Nucleus 25: 178–180.

Rocon-Stange EA (1992) Caracterização cromossômica de *Eleotris pisonis* (Perciformes, Eleotrididae). Proceedings of the IV Simpósio de Citogenética Evolutiva e Aplicada de Peixes Neotropicais, Rio de Janeiro, 1992, Rio de Janeiro, 45.

Stange EAR, Passamani M (1986) Caracterização cromossômica de *Awaous tajasica* (Lichtenstein, 1822) (Pisces, Gobiidae). Proceedings of the I Simpósio de Citogenética Evolutiva e Aplicada de Peixes Neotropicais. São Carlos, 1986, São Carlos, 59.

Subrahmanyam K (1969) A karyotypic study of the estuarine fish *Boleophthalmus boddaerti* (Pallas) with calcium treatment. Current Science 38: 437–439.

Sumner AT (1972) A simple technique for demonstrating centromeric heterochromatin. Experimental Cell Research 75: 304.

Tavolga WN (1950) Pattern variability among populations of the gobiid fish, *Bathygobius soporator*. Copeia 182–194.

Thacker CE (2003) Molecular phylogeny of the gobioid fishes (Teleostei: Perciformes: Gobioidei). Molecular Phylogenetics and Evolution 26: 354–368. doi: 10.1016/S1055-7903(02)00361-5

Thode G, Alvarez MC (1983) The chromosome complements of two species of *Gobius* (Teleostei, Perciformes). Experientia 39: 1312–1314.

Thode G, Giles V, Alvarez MC (1985) Multiple chromosome polymorphism in *Gobius paganellus* (Teleostei, Perciformes). Heredity 54: 3–7. doi: 10.1038/hdy.1985.2

Thode G, Martinez G, Ruiz JL, Lopez JR (1988) A complex chromosomal polymorphism in *Gobius fallax* (Gobiidae, Perciformes). Genetica 76: 65–71.

Uribe-Alcocer M, Arreguin JA, Padilla AT, Perez AC (1983) The chromosomes of *Dormitator latifrons* (Pisces: Gobiidae). Anales del Instituto de Biologia, Universidad Nacional Autonoma de Mexico, Serie Zoologia 10: 23–30.

Uribe-Alcocer M, Diaz-Jaimes P (1996) Chromosome complements of *Gobionellus microdon* and *Eleotris picta* collected in Mexico. Journal of Fish Biology 48: 796–798. doi: 10.1111/j.1095-8649.1996.tb01473.x

Vasil'ev VP (1985) The evolutionary karyology of fishes (=Evoljuzionnaja kariologiya ryb). Nauka, Moscow, 300 pp.

Vasil'ev VP, Grigoryan KA (1992) Karyology of fishes from the family Gobiidae. Voprosy Ikhtiologii 32: 27–40.

Vasil'ev VP, Grigoryan KA (1993) Karyology of the Gobiidae. Journal of Ichthyology 33: 1–16.

Vasil'ev VP, Vasil'yeva ED (1994) The new systematics of freshwater Caucasian gobies: three distinct species within former *N. platyrostris constructor* (Gobiidae). Proceedings of the VIII European Society Congress of Ichthyology. Oviedo, 1994, Oviedo, 66.

Vitturi R, Carbone P, Catalano E, Macaluso M (1986) Karyotypes of five species of Blennioidea (Pisces, Perciformes). Caryologia 39: 273–279.

Vitturi R, Catalano E (1989) Multiple chromosome polymorphism in the gobiid fish *Gobius niger jozo* L. 1758 (Pisces, Gobiidae). Cytologia 54: 231–235.

Wang HY, Tsai MP, Dean J, Lee SC (2001) Molecular phylogeny of gobioid fishes (Perciformes: Gobioidei) based on mitochondrial 12S rRNA sequences. Molecular Phylogenetics and Evolution 20: 309–408. doi: 10.1006/mpev.2001.0957

Webb CJ (1986) Karyology of the Indo-Pacific *Parioglossus raoi* (Herre) (Teleostei: Gobioidei) from Fiji. Australian Journal of Marine and Freshwater Research 37: 347–351. doi: org/10.1071/MF9870777

Wirth T, Bernatchez L (2001) Genetic evidence against panmixia in European eel. Nature 409: 1037–1040. doi: 10.1038/35059079

Yamada J (1967) An observation of the chromosomes in the embryonic cells of a goby, *Chaenogobius urotaenia* (Hilgendorf). Bulletin of the Faculty of Fisheries Hokkaido University 18: 183–187.