

## Northern extension of *Lesueurigobius friesii* (Malm, 1874) (Pisces: Gobiidae) distribution and the gobiid diversity decline along the Norwegian coast

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*Lesueurigobius friesii* was collected in Eidsfjorden, Sognefjorden, Norway, extending its known distribution range north as the new northernmost locality of this species. Globally, the northernmost presence of gobies is along the coast of Norway. Their diversity along the Norwegian coast showed an evident latitude gradient of gobiid diversity with a clear decrease from south to north. The significant regression structural change was found at the 63/64° N latitude band followed by a 36.4% decrease in gobiid species diversity. The species traits of gobiids north of the regression breaking point and those restricted to the south of it were compared. The only significantly more frequent characteristic of species passing north of the regression breaking point is the large depth range that reach down to the shelf break. All species present north of the point, except *Thorogobius ephippiatus* (that barely passes it) belong to *Oxudercinae* (i.e. to *Pomatoschistus* lineage of that subfamily).

**Key words:** Gobiidae, geographic distribution, Norway, species diversity

### INTRODUCTION

The family Gobiidae, with 1908 presently valid species is the largest fish family and contains the largest number of new species descriptions in the last ten years (FRICKE *et al.*, 2019). Gobies are also the only species rich fish family present in both marine and freshwater environments, while three other fish families with more than one thousand valid species are exclusively freshwater fishes. However, the majority of marine gobiid species is restricted to shallow water and to warm temperate or tropical seas where the family Gobiidae is often the most species rich family in the area, e.g. in the Red Sea (GOLANI & BOGORODSKY, 2010) or in the Mediterranean Sea (KOVAČIĆ & PATZNER, 2011). The small number of gobiid species worldwide are present at depths below the shelf break (KOVAČIĆ *et al.*, 2018), and gobiid diversity also heavily decreases in the cold temperate seas (KOVAČIĆ & SVENSEN, 2018). The northernmost presence of gobies is along the coast of Norway where representatives of this fish family enter the Arctic Circle (BYRKJEDAL *et al.*, 2016). In the rest of the world, only a few species extend north or south of latitudes greater than 50°, with *Rhinogobiops nicholsii* (Bean 1882), in the

North Pacific, reaching the highest latitude (57° 17' 26" N) among them (CSEPP & WING, 2000).

Latitudinal declines of species richness from the tropics to the poles represent a well-known spatial pattern of diversity of living organisms in marine biota (HILLEBRAND, 2004). This latitude gradient of diversity has been confirmed for Eastern Atlantic fish in general (MACPHERSON & DUARTE 1994), however, no analysis has been done for any individual fish taxa on a regional or local level along the Western European coast.

*Lesueurigobius friesii* (Malm, 1874) is an Eastern Atlantic and Mediterranean gobiid species present in the Atlantic from Mauritania to Norway (MILLER, 1986). The northernmost published distribution of this species was at Litla Døvika, Strand, Norway (BYRKJEDAL *et al.*, 2002).

The aim of the present study is to report the northernmost extension of the known distribution range of *L. friesii* and to analyze gobiid species diversity by latitude at their northernmost distribution.

## MATERIAL AND METHODS

A single specimen of *L. friesii* was collected by R. Svensen using handnet during SCUBA

diving in Eidsfjorden, Sognefjorden, Norway on 24 July 2018. The collected specimen was killed after SCUBA dives by over-anaesthetization with Quinaldine. The material is deposited in the Prirodoslovni muzej Rijeka (PMR VP4366). The morphological diagnosis is a minimum combination of characters that positively identifies fresh or preserved specimens of *L. friesii* among species of the family Gobiidae in the CLOFNAM area (MILLER, 1986; KOVAČIĆ & PATZNER, 2011; KOVAČIĆ *et al.*, 2018 and references therein). Terminology of the lateral-line system follows MILLER (1986).

The database on the latitudinal distribution of Norwegian gobiid species was compiled from the comprehensive search of the primary literature (Table 1). For the northernmost range of distribution, only the coordinates or exact geographic locality cited in the text were used and no estimation was extracted from published minimaps (e.g. MILLER, 1986; PETHON, 2005). For geographic locality without provided coordinates, the northernmost point of the recorded locality was used for coordinates. The latitudinal pattern of species richness was examined by counting all gobiid species present within one degree latitudinal bands from 58/59° N to 71/72°

Table 1. Distribution of gobies in Norway

| Species   | Distribution in Norway                             | The latitude of the northernmost distribution | Reference                       |
|---|--|---|---------------------------------|
| <i>Aphia minuta</i> (Risso, 1810)                 | Skagerrak to Trondheim                             | 63° 26' N                                     | Miller, 1986                    |
| <i>Buenia jeffreysii</i> (Günther 1867)           | Skagerrak to Trondheim, also Lofoten               | 67° 30' N                                     | Byrkjedale <i>et al.</i> , 2016 |
| <i>Crystallogobius linearis</i> (Von Düben, 1845) | Skagerrak to Lofoten                               | 68° 28' N                                     | Miller, 1986; Pethon, 2005      |
| <i>Gobius niger</i> Linnaeus, 1758                | Skagerrak to Trondheim                             | 63° 26' N                                     | Nash, 1984                      |
| <i>Gobiusculus flavescens</i> (Fabricius 1779)    | Skagerrak to Vesterålen                            | 69° 19' N                                     | Miller, 1986                    |
| <i>Lebetus scorpioides</i> (Collett 1874)         | Stavanger to Trondheim, also Lofoten and LoppHAVET | 70°34' N                                      | Byrkjedale <i>et al.</i> , 2016 |
| <i>Lesueurigobius friesii</i> (Malm, 1874)        | Skagerrak to Sognefjorden                          | 61°12'5.9" N                                  | present research                |
| <i>Pomatoschistus microps</i> (Krøyer 1838)       | Skagerrak to Trondheimsfjorden                     | 63° 51' N                                     | Miller, 1986                    |
| <i>Pomatoschistus minutus</i> (Pallas, 1770)      | Skagerrak to Tromsø                                | 69° 39' N                                     | Miller, 1986                    |
| <i>Pomatoschistus norvegicus</i> (Collett, 1903)  | Skagerrak to Lofoten                               | 68° 28' N                                     | Webb & Miller, 1975             |
| <i>Pomatoschistus pictus</i> (Malm, 1865)         | Skagerrak to Trondheimsfjorden                     | 63° 51' N                                     | Miller, 1986                    |
| <i>Thorogobius ephippiatus</i> (Lowe, 1839)       | Stavanger to Løgnin fjorden                        | 64° 22' 24" N                                 | Kovačić & Svensen, 2018         |

N. The latitudinal gradient of species richness was assessed through a regression analysis of the number of species versus latitude. The test for structural changes in the linear regression model was based on the F statistics extension of the Chow test to all potential change points (ZEILES *et al.*, 2002). The analysis tests the hypothesis that regression coefficients remain constant against the alternative that at least one coefficient varies over a series using a series of F statistics for all potential change points in an interval and rejecting the null hypothesis if any of those statistics get too large. The supF-statistic (F) with estimated p-value is calculated for the null hypothesis of no structural change. The breakpoint of the single-shift alternative will be identified if the structural change in the regression relationship is confirmed (ZEILES *et al.*, 2003). The species traits between gobiid species reaching north of the established regression breaking point and those staying restricted to the south of it were compared and differences were tested. The small sample size limits the available statistical methods (MORGAN, 2017). Significance was tested using Fisher's exact test (MCDONALD, 2014) as the significance of differences in frequencies of a particular trait between species present north of the breaking point and species restricted to the south of it. A 5% level of significance was selected for the evaluation of the tests.

The regression analysis, the test for structural changes in linear regression relationships, and Fisher's exact test were performed in R software version 3.3.3 using RStudio 1.0.143 integrated development environment (IDE) for R and the Strucchange package, version 1.5-1.

## RESULTS

### *L. friesii* distribution

Material collected (standard length+caudal fin length): single male, 56.8+17.0 mm, PMR VP4366, Eidsfjorden, south-east of the town Sogndal in Sognefjorden, Norway (61°12'5.9" N, 7°10'6.6" E), 24th July 2018, collector R. Svensen (Fig. 1a). Species diagnosis: (1) sub-



Fig. 1. *Lesueurigobius friesii*: a) single male, 56.8+17.0 mm, PMR VP4366, b) one of observed additional specimens, both at Eidsfjorden, south-east of the town Sogndal in Sognefjorden, Norway. Photographs by M. Kovačić (a) and R. Svensen (b)

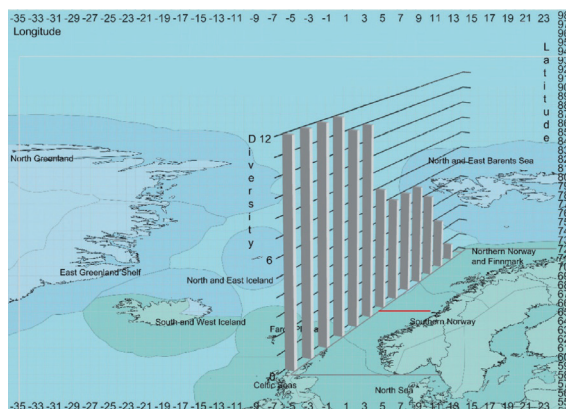


Fig. 2. The gobiid species diversity by latitude for one degree latitudinal bands from 58/59° N to 71/72° N along the Norwegian coast. The delimited and labeled marine ecoregions in the area (Spalding *et al.* 2007). The regression breaking point is indicated by red line after 63/64° N band. The map was modified from Shorthouse (2010)

orbital papillae of the lateral-line system with longitudinal row a; (2) pelvic disc with anterior membrane; (3) head canals absent; (4) suborbital transversal rows absent; (5) nape scaled; (6) pectoral fin with 18-19 rays (present specimen 18). Ecological data: The specimen was collected at 22 m depth on a muddy sandy bottom. The additional specimens were noticed and photographed (Fig. 1b). Geographical distribution: The present record extends the northernmost species distribution from Litla Døvika, Strand, Rogaland to Eidsfjorden, Sognefjorden (i.e. from 59°07' N to 61°12'5.9" N) (Table 1).

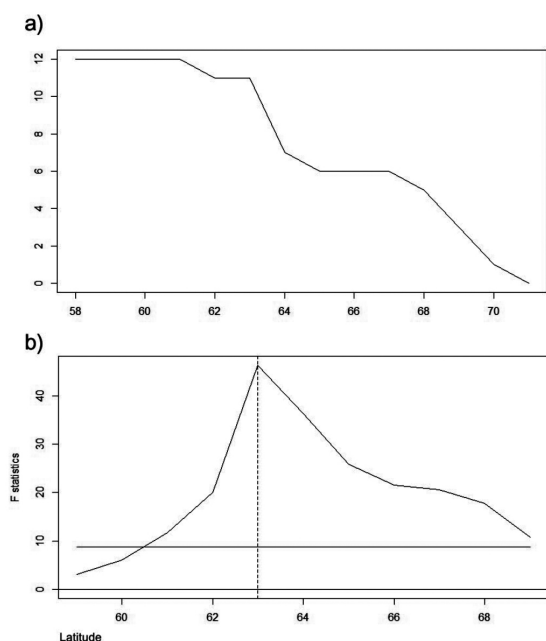


Fig. 3. Test for structural changes: a) original data, b) *F* statistics, red line corresponds to a *supF* test at the 5% significance level, the identified regression breaking point as dotted line

#### ***Latitude distribution and species diversity of gobies along the Norwegian coast***

The diversity of gobies along the Norwegian coast showed a clear decrease from twelve species at the southernmost latitude band (58/59° N) to no gobies present at the northernmost latitude band (71/72° N) (Table 1, Fig. 2). The linear regression model has a highly significant negative regression present and a large portion of the species diversity change is explained by the latitudinal component (intercept  $a=70.94\pm 5.08$ , slope  $b=-0.99\pm 0.08$ , coefficient of determination  $R^2=0.93$ , *F*-statistic  $F=156.8$ , probability  $p<0.001$ ). The breakpoint analysis identified the 63/64° N band as the significant regression structural change point. The decrease in species diversity between 63/64° N and the next band is 36.4% ( $F=46.344$ , probability  $p<0.001$ ) (Fig. 3).

#### ***The traits of gobiid species reaching north of the regression breaking point***

The species traits of gobiids reaching north of the regression breaking point and those

restricted to south of it are presented and compared in Table 2. The high difference in presence of some species traits were observed between species reaching north of the point of the abrupt species diversity change and those restricted to the south: gobiid species reaching north of the point almost all belong to Oxudercinae (vs. mostly Gobiinae gobies among species restricted to the south of it); with their lower depth limit, almost all of them are able to reach the shelf break (vs. none being able to reach the shelf break among species restricted to the south of it); almost all are annual or biannual (vs. more mixed longevity composition); and they are mostly very small in size, i.e. less than 60 mm, (vs. only one species being very small among those restricted to the south of it) (Table 3). The frequencies of traits were tested for significant differences. Despite differences in frequencies of these traits between gobiid species reaching north of the regression breaking point and those restricted to the south, the significantly different frequency by Fisher's exact test was observed only for the species lower depth limit (Table 3).

## **DISCUSSION**

The gobiid diversity along the Norwegian coast showed an evident decrease in diversity from south to north with a single strong decrease of 36.4% at one particular part (*i.e.* between 63/64° and 64/65° N latitude bands). The northward decrease could be expected from the known latitudinal declines of species richness for living organisms or just for fishes over broad latitudinal ranges (MACPHERSON & DUARTE, 1994; HILLEBRAND, 2004). However, the research covering the restricted area with a similar latitudinal range as the present research (56-71° N) showed no evidence of a latitudinal cline in alpha, beta or gamma diversity of macrobenthos along the Norwegian coast (ELLUNGSEN & GREY, 2002). No similar single breaking point of species diversity decrease along the Norwegian coast was recorded for any other animal taxa like the presently observed decrease for gobies between 63/64° and 64/65° N latitude bands. The point of the abrupt gobiid species diversity

Table 2. The species traits of gobiid species. The species restricted to south above mid-table line, those reaching north of the regression breaking point below mid-table line. Data from Gibson & Ezzi, 1981; Fabi & Giannetti, 1985; Miller, 1986; Moreira *et al.*, 1991; Arruda *et al.*, 1993; Iglesias & Morales-Nin, 2001; Ahnelt & Dorda, 2004; Beldade *et al.*, 2006; Kovačić & La Mesa, 2010; Herler *et al.*, 2014; Stern *et al.*, 2018. The longevity of *B. jeffreysii* was estimated from age of sister species *B. affinis* Iljin, 1930

| Species               | Taxonomy    | Depth range (m) | Geographic distribution     | Bottom preferences               | Longevity (y) | Maximum size (mm) |
|-----------------------|-------------|-----------------|-----------------------------|----------------------------------|---------------|-------------------|
| <i>A. minuta</i>      | Gobiinae    | 5-90            | cold and warm temperate sea | nectonic                         | 1             | 79                |
| <i>G. niger</i>       | Gobiinae    | 1-96            | cold and warm temperate sea | epibenthic various bottom        | 5             | 150               |
| <i>L. friesii</i>     | Gobiinae    | 10-130          | cold and warm temperate sea | epibenthic soft sediment         | 11            | 130               |
| <i>P. microps</i>     | Oxudercinae | 0-12            | cold and warm temperate sea | epibenthic soft sediment         | 2             | 64                |
| <i>P. pictus</i>      | Oxudercinae | 1-55            | cold and warm temperate sea | epibenthic soft sediment         | <3            | 57                |
| <i>B. jeffreysii</i>  | Oxudercinae | 5-330           | cold temperate sea          | epibenthic various bottom        | 1             | 60                |
| <i>C. linearis</i>    | Oxudercinae | 1-400           | cold and warm temperate sea | nectonic                         | 1             | 47                |
| <i>G. flavescens</i>  | Oxudercinae | 0-20            | cold and warm temperate sea | hyperbenthic                     | 2             | 60                |
| <i>L. scorpioides</i> | Oxudercinae | 30-375          | cold temperate sea          | epibenthic various bottom        | 2             | 39                |
| <i>P. minutus</i>     | Oxudercinae | 2-200           | cold and warm temperate sea | epibenthic soft sediment         | <3            | 95                |
| <i>P. norvegicus</i>  | Oxudercinae | 18-325          | cold and warm temperate sea | epibenthic soft sediment         | <3            | 72                |
| <i>T. ehippiatus</i>  | Gobiinae    | 6-40            | cold and warm temperate sea | epibenthic hard and mixed bottom | 9             | 130               |

Table 3. The frequencies of species traits between species present north of the regression breaking point and species restricted south of it and the results of Fisher's exact test on these frequencies (\* indicates significant *p*-values <0.05)

|                               | Taxonomy    |          | Lower depth limit    |                          | Lifespan                   |                     | Size            |                 |
|-------------------------------|-------------|----------|----------------------|--------------------------|----------------------------|---------------------|-----------------|-----------------|
|                               | Oxudercinae | Gobiinae | Reaching shelf break | Not reaching shelf break | Annual or biannual species | Multiannual species | Less than 60 mm | More than 60 mm |
| Restricted south of the point | 2           | 3        | 0                    | 5                        | 3                          | 2                   | 1               | 4               |
| Reaching north of the point   | 6           | 1        | 6                    | 1                        | 6                          | 1                   | 4               | 3               |
| Fisher's exact test (p-value) | 0.2222      | 0.01515* |                      | 0.5227                   |                            | 0.2929              |                 |                 |

change also shows no match with boundaries of known marine ecoregions, since it is nested deep inside the Southern Norway ecoregion, distant from its boundary to Northern Norway and Finnmark (Fig. 2). It also shows no match with the boundaries of large marine ecosystems, being nested deep inside the Norwegian Shelf Large Marine Ecosystem (LME) (SPALDING *et al.*, 2007; SHERMAN & HEMPEL, 2009).

The evident northward decrease of gobiid species diversity is hard to question from the presented data as the real gobiid species distribution in nature. However, the strong decrease at 64° N latitude as the real pattern in nature can be questioned and consequently tested in the future by researches north of the regression breaking point. It can be challenged by two alternative “lack of research” hypotheses: that there is no point in the abrupt species diversity change at all (i.e. the uniform decrease of gobiid diversity exists from that point toward the north), or that the abrupt diversity decrease point is placed farther north than what has been discovered now. Both alternative hypotheses presume that species recorded just south of the 64° N latitude are present but not yet recorded north of it. The researches of Norwegian gobies have not been intensive, with only a few recently published ichthyological papers focused exclusively on diversity and biogeography of this taxon (BYRKJEDAL *et al.*, 2002; 2016; KOVAČIĆ & SVENSEN, 2018). However, the majority of species now restricted to the south are more easily detected and recorded than most of the species able to reach farther north, e.g. *Gobius niger* Linnaeus, 1758, *L. friesii*, and *Thorogobius ephippiatus* (Lowe, 1839) (that barely passes the regression breaking point) are much larger and more intensively colored than “north extended” species, while *Pomatoschistus microps* (Krøyer, 1838) and *Pomatoschistus pictus* (Malm, 1865) can be numerous in very shallow water and therefore hard to overlook (Table 2). This is contrary to the expectation that the low research effort, if that is the case to the north, would first recognize easily detected species.

It could be expected that the clear decrease in gobiid species diversity going north at this small

scale at high latitudes (i.e. along the Norwegian coast), is related to the general warm temperate to tropical characteristic of this taxon. It is known that among the possible environmental factors that can explain the latitudinal pattern of species richness for benthic fishes and invertebrates, the sea-surface temperature (SST) is the best predictor showing a positive relationship with diversity (MACPHERSON, 2011). However, no pattern of northward decreases in long term winter average SST along the entire Norwegian coast and along the Norwegian Coastal Current (NCC) is visible, and there is no strong temperature decrease south to north of 64° N latitude that could match the gobiid species diversity decreasing point (SÆRTRE *et al.*, 2003). On the contrary, the long term winter average SST increases from the most southern stations northwards, being highest, i.e. about 5° C, both north and south around the point of the strong gobiid species diversity change, finally decreasing again at the Norway northernmost stations (Fig. 2 and Table 2 in SÆRTRE *et al.*, 2003). There is obviously no easy answer which environmental factor or their combination shapes the latitudinal decrease of gobiid species richness and established regression breaking point along the Norwegian coast.

The significant difference in depth range was noticed between species reaching north of the regression breaking point and those restricted to the south of it. All species that are able to reach as deep as the shelf break were able to extend their distribution north of the abrupt species diversity change, and only one species that is restricted to shallow waters, *Gobiusculus flavescens* (Fabricius, 1779), has managed to extend its distribution north as well (Table 2). It is not clear if the species are able to adapt in the north because the adaptations developed for deep waters help also with survival in the north waters, or deep waters in the north provides some kind of refuge for survival of gobiid populations at these high latitudes in extreme moments. There are a few traits prevailing in species able to reach north of the regression breaking point but failing to be significantly more frequent among them than in the south

limited species. All of these species traits are more or less shared within a single taxonomic or phylogenetic group (Table 2). All species north of the regression breaking point, except *T. ephippiatus* (that barely passes it), belong to Oxudercinae, i.e. to the *Pomatoschistus* lineage of that subfamily (AGORRETA *et al.*, 2013), which is the only branch of Oxudercinae present in European seas and furthermore with distribution also limited only to these seas. Species of the *Pomatoschistus* lineage are generally annual or biannual species and on the average small sized, contrary to almost all species (except *A. minuta*) of two Gobiinae lineages present in Norwegian waters. Oxudercinae are tropical and temperate sea gobies and mostly inhabit estuaries with some freshwater species (from PEZOLD, 2011), there as Gobionellidae). Contrary to the *Pomatoschistus* lineage, Oxudercinae in general are

not restricted to a short lifespan and small size. It appears that the evolution of the *Pomatoschistus* lineage has developed the unique potential among Oxudercinae to deal with deep waters and high latitudes, while the latter is also unique among Gobiidae in general. However, presently it is not clear which of the biological or ecological characteristics shared within the taxon help that capability.

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## Najsjeverniji nalaz glavoča repaša *Lesueurigobius friesii* (Malm, 1874) (Pisces: Gobiidae) i smanjivanje raznolikosti glavoča uzduž Norveške obale

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### SAŽETAK

Glavoč repaš *Lesueurigobius friesii* sakupljen je u Eidsfjorden, Sognefjorden, Norveška, što predstavlja najsjeverniji nalaz ove vrste. Globalno, najsjevernija rasprostranjenost glavoča nalazi se uz obale Norveške. Raznolikosti vrsta glavoča jasno se smanjuje od juga prema sjeveru uzduž Norveške obale. Statistički značajna strukturna promjena regresije utvrđena je na pojasu 63/64° sjeverne zemljopisne širine popraćena 36.4% smanjenjem raznolikosti vrsta glavoča. Osobine vrsta glavoča sjeverno od točke loma regresije uspoređene su s osobinama vrsta ograničenim južno od nje. Jedina značajno češća osobina vrste glavoča koje prolaze sjeverno od točke loma regresija je veći raspon dubina, koji kod ovih vrsta seže do ruba kontinentske podine. Također sve vrste sjeverno od točke loma, osim vrste *Thorogobius ephippiatus* (koja je jedva prolazi), pripadaju potporodici Oxudercinae, točnije *Pomatoschistus* grupi te potporodice.

**Ključne riječi:** Gobiidae, zemljopisna rasprostranjenost, Norveška, raznolikost vrsta