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A review of the ecological knowledge on the species *Batrachoides liberiensis* in estuarine and lagoon environments of West Africa

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Abstract

Scientific fishing programmes were carried out between 1979 and 2013 in several West African estuarine, coastal and lagoon ecosystems. *Batrachoides liberiensis* represented only 5.2% of the occurrences, of which the majority were recorded in the Sine Saloum estuary. This originality makes it possible to use this population to characterise certain features of the biology and ecology of this little described species. *B. liberiensis* was recorded in waters with a salinity of 25–46, transparency of 1–3.5 m, at depths of 2–10 m. It was particularly abundant in areas at a distance of 15–35 km from the mouth. The water temperature did not appear to be a determining factor for this species. The sex ratio of the population, whose total length ranged from 10 to 371 mm, was in favour of females (87%) with an estimated size at first maturity of 189 mm (total length). The parameters of the length-weight relationship were estimated at $K = 1.0009 \times 10^{-5}$ and $b = 3.097$. The diet of *B. liberiensis* consisted mainly of molluscs and crabs, present in respectively, 53.6% and 50.7% of the stomach contents analysed.

KEYWORDS

Batrachoides liberiensis, batrachoididae, hairy toadfish, tropical estuary, tropical lagoon, West Africa

Résumé

Des programmes de pêche scientifique ont été réalisés entre 1979 et 2013 dans plusieurs écosystèmes estuariens, côtiers et lagunaires d'Afrique de l'Ouest. *Batrachoides liberiensis* ne représentait que 5,2 % des cas, dont la majorité a été enregistrée dans l'estuaire du Sine Saloum. Cette singularité permet d'utiliser cette population pour caractériser certains traits de la biologie et de l'écologie de cette espèce peu décrite. *B. liberiensis* a été enregistré dans des eaux ayant une salinité comprise entre 25 et 46, une transparence allant de 1 à 3,5 m, à des profondeurs de 2 à 10 m. Cette espèce était particulièrement abondante dans les zones situées à une distance de 15 à 35 km de l'embouchure. La température de l'eau ne semblait pas être

[†]Deceased.

un facteur déterminant pour cette espèce. La répartition par sexe de la population, dont la longueur totale allait de 10 à 371 mm, était en faveur des femelles (87 %) avec une taille estimée à la première maturité de 189 mm (longueur totale). Les paramètres de la relation longueur-poids ont été estimés à $K = 1,0009 \cdot 10^{-5}$ et $b = 3,097$. Le régime alimentaire de *B. liberiensis* se compose principalement de mollusques et de crabes, présents respectivement dans 53,6 % et 50,7 % des contenus stomacaux analysés.

1 | INTRODUCTION

Estuarine environments are original ecosystems that are part of both the marine and continental realms. These ecosystems are commonly inhabited by marine species, freshwater species and species endemic to these environments. In the absence of anthropogenic interventions (pollution, development, resource exploitation, etc.), the biomass produced by estuarine ecosystems is exceptionally high (Elliott et al., 2007). These environments are at the origin of numerous food chains (Potter et al., 2015). They are also an irreplaceable breeding and feeding ground for many species (Martinho et al., 2007; Vidy, 2000).

Since the 1980s, several research projects have focused on fish populations in coastal, estuarine and lagoon environments in West Africa (Figure 1) as well as their hydro-climatic environment. Studies have been conducted on the Ebrié Lagoon in Côte d'Ivoire (Albaret, 1994), the Fatala and Dangara estuaries in Guinea (Baran, 1995), the Gambia estuary in The Gambia (Albaret et al., 2004; Simier et al., 2006; Vidy et al., 2004), the Sine Saloum estuary complex in Senegal (Diouf, 1996; Ecoutin et al., 2010; Ecoutin et al., 2013; Ecoutin et al., 2014; Sadio et al., 2015; Simier et al., 2004; Vidy, 2000), the Bijagos Islands and the Rio Buba estuary in Guinea Bissau (Deme-Gningue et al., 1994; Diouf et al., 1994; Sadio, 2015) and the coastal zone of the Banc d'Arguin National Park in Mauritania (Sadio, 2015). All the resulting data have been incorporated in an information system entitled "Fish communities and artisanal fisheries of West African estuarine, lagoon and freshwater ecosystems" (French acronym PPEAO) (<http://ppeao.ird.fr> - Simier et al., 2019a).

These data have made it possible to conduct syntheses of the ecology and biology of certain species or groups of fish species including Mugilidae (Albaret & Legendre, 1985), Gerreidae (Albaret & Desfossez, 1988), the shortfin pompano *Trachinotus teraia* (Trebaol, 1991), the bongo shad *Ethmalosa fimbriata* (Charles-Dominique & Albaret, 2003), the bobo croaker *Pseudotolithus elongatus* (Carassou, 2003) and Ariidae (Simier et al., 2021). The aim of the present work was to deepen our knowledge of the distribution and ecology in West African estuarine ecosystems of the hairy toadfish *Batrachoides liberiensis* (Steindachner, 1867), a marine species, usually breeding at sea, but making extensive use of the estuarine environment, yet very scarce. First, we assess the presence and the distribution of *B. liberiensis* in six estuarine ecosystems from Côte

d'Ivoire to Mauritania. Secondly, we focus on its spatial preferences in terms of distance from the mouth of the estuary and its environmental preferences in terms of water salinity, temperature, transparency and depth. Finally, we use its size structure, its length-weight relationship, and information on its reproduction and trophic behaviour to provide a better understanding of the ecology of this poorly known species.

2 | MATERIAL AND METHODS

2.1 | Description of the species

Batrachoides liberiensis belongs to the order Batrachoidiformes and the family Batrachoididae. According to Collette and Russo (1981), this demersal species lives in the tropical waters off the Atlantic coast of Africa from Senegal to northern Angola (14°N–17°S). It inhabits marine, coastal or brackish waters. Although described throughout this coastal region (Froese & Pauly, 2021), *B. liberiensis* is not of great ecological or economic importance. It is not a target species for fisheries, partly because of its low abundance and partly because of its rather small size, its total length being maximum 46 cm (Schneider, 1990). In the family Batrachoididae, it is the only species of the genus *Batrachoides* found in the eastern Atlantic, the other eight known species in this genus being found in the western Atlantic and Pacific, on either side of the Isthmus of Panama (Collette & Russo, 1981; Greenfield et al., 2008). For this reason, it is considered by Collette and Russo (1981) to be representative of the primitive condition of the genus *Batrachoides*. *B. liberiensis* is often described by its common name hairy toadfish. In African vernacular terminology, this species has not often been identified.

2.2 | Data collection

The data used in this work were collected by researchers from IRD (*Institut Français de Recherche pour le Développement*) during experimental fishing surveys carried out between 1979 and 2013 as part of different research projects on estuarine, lagoon and coastal fish assemblages in several West African countries (Figure 1). The sampling protocols implemented are described in documents accessible on the

PPEAO information system (Simier et al., 2019b). Whatever the sampling protocol, each fishing operation is documented with data on the sampling station (geographical coordinates, depth of the station and distance to the mouth) as well as the physico-chemical environment of the fishing operation (water temperature, salinity, water transparency). Only fishing operations using fyke nets in the Sine Saloum estuary between 1995 and 1997 did not include physico-chemical measurements. The methodology for collecting information on the species was always the same. All captured fish were identified to species level. Almost all *B. liberiensis* individuals were measured to the nearest millimetre (total length) when collected, and some were weighed to the nearest gram. Often, their sex was determined and their stage of maturity was evaluated according to the maturity scale established by Albaret and Legendre (1985). Information on stomach contents was also provided for some individuals.

2.3 | Data analysis

Statistical analyses and graphs were carried out with R software (R Core Team, 2021). Linear regressions of $\log(W)$ vs. $\log(TL)$, where W is total weight in g and TL is the total length in mm, were calculated to obtain the length-weight relationship of the form $W = K \cdot TL^b$ (Froese, 2006) where $\log(K)$ is the intercept and b is the slope of the log-log regression. Individuals considered as outliers in the first step involving all data were removed before the second regression to improve the quality of the fit. The size at first maturity (total length at which 50% of the individuals are mature or TL_{50}) could only be estimated for females of *B. liberiensis* in the Sine Saloum estuary. This was done by logistic regression after

grouping the individuals into 1 cm size classes and calculating the percentage of mature individuals in each class.

2.4 | Ethical statement

The scientist in charge of data collection and fish manipulation holds the “University Diploma in Animal Experimentation, Level II Accreditation n° I-51UFRReims-S2-09 from the University of Reims Champagne-Ardennes” and the “Animal Experimentation School Diploma – Design and implementation of experimental procedures at the Laboratory of Animal Physiopathology and Functional Pharmacology at ONIRIS – Ecole Nationale Vétérinaire, Agroalimentaire et de l’Alimentation Nantes Atlantique,” which ensures that animal welfare was respected during the faunal surveys. No harsh practices or chemicals were used to immobilise or kill the fish before handling. Measurement, weighing and observation of gonads and stomach contents were done after the fish were dead. No specimens were processed alive.

3 | RESULTS

3.1 | General information

A total of 261 species were caught in all the sampling programmes conducted in estuarine, coastal or lagoon ecosystems in West Africa described in the PPEAO information system. The species *B. liberiensis* was recorded in 184 fishing operations, that is, 5.2% of the fishing

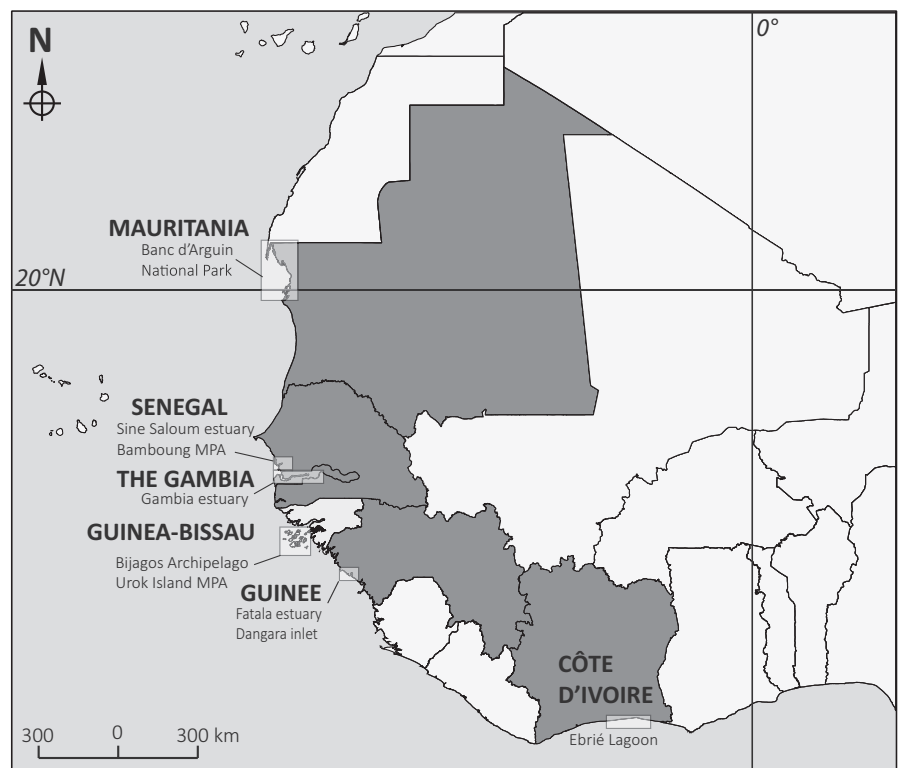


FIGURE 1 Map of West Africa showing the countries and ecosystems studied

operations and 310 individuals were collected. In view of the 3514 fishing operations carried out in these different ecosystems and the more than 217,000 individuals recorded (Simier et al., 2019a), it seems clear that *B. liberiensis* is not a well-represented species in these environments, regardless of the selectivity problems of the fishing gear used.

B. liberiensis was recorded in four of the six estuarine, coastal or lagoon ecosystems studied: the Sine Saloum estuary in Senegal, the Gambia estuary in The Gambia, the islands of the Bijagos archipelago in Guinea Bissau and the Fatala estuary and the Dangara inlet in Guinea (Table 1). It has not been recorded in the Banc d'Arguin (Mauritania) nor in the Ebrié Lagoon (Côte d'Ivoire) despite the large number of fishing operations carried out in the latter ecosystem (Table 1). In fact, this species has only been really well recorded in the Sine Saloum estuary (Senegal) where it was caught in 9.1% of fishing operations. Small numbers were recorded in the Gambia estuary (1.8% of fishing operations) and occasionally in Guinea and Guinea Bissau (1% of fishing operations) (Table 1).

In each fishing operation in which the species was present, between 1 and 11 individuals were recorded, with only one or two individuals caught in 86.4% of these operations (one individual in 69.6% and two individuals in 16.8%).

3.2 | Spatial preferendum

In the Sine Saloum estuary, 90% of occurrences of *B. liberiensis* were recorded at a distance of between 15 and 35km from the mouth.

Farther than 35km and less than 15km from the mouth, this species was very rarely recorded. The proportion of fishing trips with *B. liberiensis* in classes of 5 km from the mouth and up to 60km confirmed that this proportion was not homogeneous (Chi-squared = 48.096, $p = 3.008 \cdot 10^{-6}$): it was 17.7% between 15 and 20km, 8.3% between 20 and 25km, 12.3% between 25 and 30km and 14.2% between 30 and 35km, while it did not exceed 6% between 0 and 15km and between 35 and 60km. In the Gambia estuary, *B. liberiensis* was recorded a few times beyond 50km, but its very moderate abundance in this estuary (Table 1) puts these data into perspective. Its very low abundance in the other ecosystems made it impossible to analyse this variable.

3.3 | Environmental preferendum

The minimum, maximum and mean values of bottom salinity, bottom temperature, transparency and depth for the fishing operations in which *B. liberiensis* were caught are listed in Table 2, together with the range containing 90% of these observations of *B. liberiensis* and the total range of values recorded in the PPEAO information system.

Low transparency (<1 m) was recorded in Guinea (4/4 of observations) and The Gambia (7/8). Low salinity (<22) was also recorded in Guinea (2/4) and The Gambia (4/8).

According to the range of environmental parameters archived in the PPEAO information system, with the exception of temperature, the preferential range (90%) of *B. liberiensis* is limited.

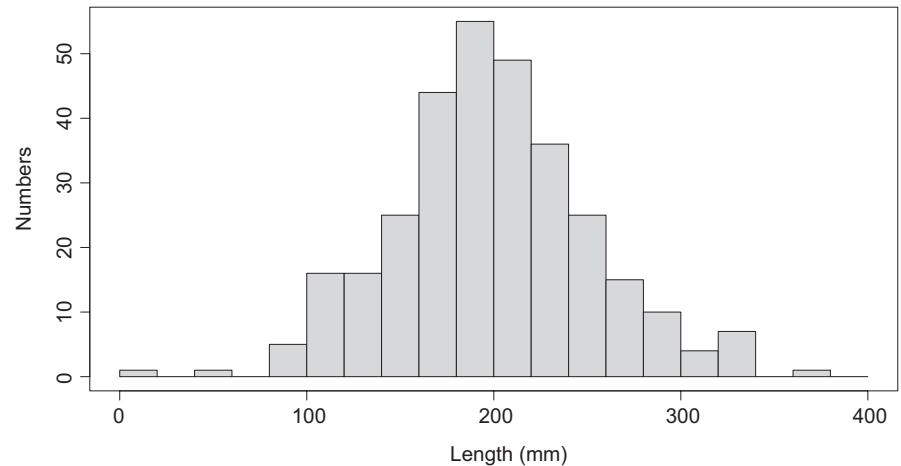
TABLE 1 Data on *Batrachoides liberiensis* in the PPEAO information system: Country, study period, number of fishing operations, number of operations in which *B. liberiensis* was caught, percentage of operations in which *B. liberiensis* was caught, number of individual *B. liberiensis* caught

Country	Sampling period	Total number of fishing operations	Number of fishing operations with <i>B. liberiensis</i>	% of fishing operations with <i>B. liberiensis</i>	Number of individuals of <i>B. liberiensis</i>
Mauritania	2008–2010	86	0	0	0
Senegal	1990–2012	1848	169	9.1	293
The Gambia	2001–2003	562	10	1.8	12
Guinea-Bissau	1993/2011–2013	102	1	1	1
Guinea	1990–1993	373	4	1	4
Côte d'Ivoire	1979–1984	543	0	0	0
Total		3514	184	5.2	310

TABLE 2 Environmental preferendum for *Batrachoides liberiensis*: Number of fishing operations, number of individuals, minimum, maximum and mean values, range where 90% of the observations were recorded, total range in the PPEAO information system

	Number of fishing operations	Number of individuals	Minimum	Maximum	Mean	90%	Total range
Bottom salinity	132	236	5	55	37.2	25–46	0–135
Bottom temperature (°C)	132	235	22.3	31.8	28.2	24–31	21.2–33
Transparency (m)	128	230	0.2	4.5	2.24	1.0–3.5	0.07–5.4
Depth (m)	131	236	1	12.5	5.70	2–10	0.6–22

FIGURE 2 Size frequency distribution (per 20mm class) of *B. liberiensis*



3.4 | Size structure

The size structure distribution of the 310 individual fish measured ranged from 10 to 371 mm (TL) (mean 200.3 mm \pm 53.4 mm). This distribution was unimodal with a mode at 198 mm (Figure 2). Half the individuals measured between 167 and 234 mm. In Guinea and Guinea Bissau, the few individuals recorded were all small, less than 120 mm. The maximum size of 371 mm was recorded in the Sine Saloum estuary.

3.5 | Length-weight relationship

The relationship between total length (mm) and weight (g) calculated for 218 male and female individuals, measuring between 50 and 328 mm and weighing between 2 and 630 g, provided the parameters $K = 1.0009 \times 10^{-5}$ and $b = 3.097 (\pm 0.0297)$ with a correlation coefficient $r = 0.99$.

3.6 | Reproduction

In the Sine Saloum estuary, the sex of 131 individuals covering the entire length range (84–328 mm) was recorded. Among these individuals, the sex of 31 individuals (≤ 230 mm) could not be determined. For the individuals where the sex was differentiated, the sex ratio (SR) was very favourable to females (87% females, SR = 6.7 females for one male). Among these females, 45% were maturing or mature. The smallest female at the beginning of sexual maturation measured 140 mm. No females were recorded at the spawning or spent stage.

Among 87 females measuring between 140 and 305 mm collected in the Sine Saloum estuary, of which 34 were mature, the size at first maturity was estimated at 189 ± 22.1 mm. Occasional reports indicate the presence of eggs 5–6 mm in diameter. The sexually mature individuals were recorded between January and August, which represents the entire dry season in this region of Senegal and includes the beginning of the rainy season.

3.7 | Trophic behaviour

In the Sine Saloum estuary, that is, the only ecosystem in which this information was collected, the stomach contents of 69 individuals (measuring between 131 and 286 mm) were examined during sampling. The stomach contents of 87.3% of these individuals comprised only one food category. In all, six categories of food were recorded: molluscs (53.6% of observations), mainly bivalves (29%), crabs (50.7%) and exceptionally fish, echinoderms and various plant debris.

4 | DISCUSSION

These results confirm the sparse information already collected on the biology and ecology of the species *Batrachoides liberiensis*. With the exception of the Sine Saloum estuary, it is indeed a rare species since it is seldom recorded in the other ecosystems where it is known to occur.

4.1 | Biological aspects

The maximum length of *B. liberiensis* caught in the Sine Saloum estuary was 371 mm (TL). Individuals collected by Udo et al. (2017) from landings of distant water boats at Ibeno, in the Qua Iboe River estuary (Nigeria), did not exceed 130 mm. In 2015, however, the same authors reported a maximum length of 233 mm (TL) from landings at Ibeno Town, of distant water vessels off the Qua Iboe River estuary, South-eastern Nigeria (Udo & Udoh, 2015). A maximum length of 245 mm (TL) was given by Collette (2016) in the FAO species identification guide for the living marine resources of the Eastern Central Atlantic. In the Field Guide to the commercial marine resources of the Gulf of Guinea, Schneider (1990) estimated that this species could reach 460 mm (TL). Therefore, except for Schneider's (1990) estimation, the maximum length measured in the Sine Saloum estuary is the largest recorded on the West African coast.

The length–weight relationship estimated for a sample of male and female individuals between 50 and 328 mm ($W = 1.0009 \times 10^{-5} TL^{3.097}$, $r = 0.99$), where W is the body weight in g and TL is the total length in mm, differs from that reported by Udo et al. (2017) for a sample of 31 *B. liberiensis* females measuring between 8 and 13 cm, collected in the Qua Iboe River estuary (Nigeria): $W = 0.0582 TL^{2.3327}$ ($r = 0.8466$), where TL is expressed in cm. For $TL = 10$ cm, the weights estimated by our relationship and that of Udo et al. (2017) are 15.7 g and 12.5 g respectively. Our sample covers a wider size range and a larger number of individuals.

In the Sine Saloum estuary, the size of the smallest female recorded at the beginning of sexual maturation was 140 mm (TL) and no females were recorded at spawning stage. A length of 122 mm (SL , or an estimate of 145 mm TL) was reported by Collette and Russo (1981) in Ghana for a female at spawning stage.

The diet of *B. liberiensis* documented in the present study was primarily carcinophagous and malacophagous, and secondarily piscivorous. This species is generally considered to be benthophagous, and was reported to consume zoobenthos, crustaceans and crabs (Collette & Russo, 1981), mainly crabs (Collette, 2016), shrimps and fish (Diouf, 1996). In the stomach contents of individuals caught in the estuary of the Qua Iboe River in Nigeria, Udo and Udoh (2015) noted the dominance of fish, followed by crustaceans. This confirms a predatory diet for *B. liberiensis*, with a generalist tendency, and consumption of molluscs apparently particularly favoured according to the data we analysed.

4.2 | Geographical distribution, scarcity

According to Albaret's (1999) classification, *B. liberiensis* belongs to the category of marine accessory species, that is, relatively rare and not reproducing in estuarine areas, its presence there being limited in time and/or space. According to Whitfield's (2005) classification, it is a marine migrant, that is, a marine fish species that usually breeds at sea, with the juveniles and/or adults making extensive use of the estuarine environment. The juveniles of many of these species show varying degrees of dependence on estuaries as nursery areas.

Little work has been done on *B. liberiensis*; only a few articles describing coastal or estuarine fish populations report its presence. In West Africa, *B. liberiensis* has been recorded on rare occasions in the Banc d'Arguin in Mauritania (one individual measuring 10.5 cm – Gushchin & Fall, 2012), on an artificial reef in Yenne, a coastal village in Senegal (one individual measuring 20 cm – Terashima et al., 2007), in the mouth of the Gambia River, in the Tanbi Wetland National Park, where the species represented between 0.1% and 0.2% of total abundances (Ceesay et al., 2016). It is usually only recorded in inventory catalogues, for example, in Sierra Leone (Kamara, 1977) and Ghana (Ofori-Adu, 1988) or in papers on the taxonomy of fish species (Collette & Russo, 1981; Fisher & Scialabba, 1988; Roux, 1990).

On the continental shelves adjacent to the estuarine and lagoon areas studied, this scarcity was confirmed by the results of

experimental fishing surveys in these coastal areas. Although identified on the Senegalese-Gambian shelf (Froese & Pauly, 2021), *B. liberiensis* was almost never caught during the numerous scientific trawl surveys conducted in the 1970s and 1980s (Caverivière et al., 1988; Domain, 1980). The species was caught in small numbers during scientific fishing surveys on the coastal shelves of Guinea Bissau (Domain, 1989), Guinea (Domain et al., 1999), Côte d'Ivoire (Caverivière, 1993; Troadec et al., 1969) and Togo (Lhomme, 1984). A higher abundance of this species seems to be indicated in the Qua Iboe river estuary (Nigeria), through the work of Udo and Udoh (2015) and Udo et al. (2017).

When explaining why the ovaries of *B. liberiensis* are larger in the Qua Iboe River estuary than on the coastal shelf, Udo et al. (2017) suggested that the differences could be partly explained by differences in the food and in the environment. It is therefore possible that the food supply and environmental conditions are better in the estuary than in the coastal ecosystem.

The relatively high abundance of *B. liberiensis* in the Sine Saloum estuary revealed by our study should therefore be highlighted. What are the particularities of this estuary that allow this species to flourish there? In the Sine Saloum estuary, *B. liberiensis* was present in more than 1 of 10 fishing operations. Its preferred spatial zone was between 15 and 35 km from the mouth. Beyond 35 km, salinity in the fluvial part of the Saloum can increase to more than 140 (Diouf, 1996). The maximum tolerance of *B. liberiensis* to salinity (around 55) therefore limits its extension upstream. The higher abundance of *B. liberiensis* in the zone between 15 and 35 km from the mouth could be directly linked either to a stable physico-chemical environment or to the presence of plentiful food resources. This would be in line with the hypothesis put forward by Udo et al. (2017). However, due to the limited data available on the estuary and the lack of data on the nearby coastal shelf, this remains a hypothesis.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

All data used for this work are freely available on request at www.ppeao.ird.fr.

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