1 **Hydrography of shellfish harvesting areas in the western Cantabrian coast (Rías Altas, NW**
2 **Iberian Peninsula)**

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4 José Daniel Cerdeira-Arias^{1,*}, Jaime Otero², Elena Barceló³, Guillermo del Río⁴, Aitor Freire⁵,
5 Manuel García⁶, Miguel Ángel Nombela⁷, Gloria Portilla⁸, Natalia Rodríguez⁹, Gabriel Rosón⁷,
6 José Antonio Santiago¹⁰, Xosé Antón Álvarez-Salgado²

7

8 ¹Xefatura Territorial da Consellería do Mar, Avda. Gerardo Harguindey Banet 2, 27863 Celeiro,
9 Viveiro, Lugo, Spain

10 ²CSIC Instituto de Investigaciones Marinas, Eduardo Cabello 6, 36208 Vigo, Pontevedra, Spain

11 ³Asistencia Técnica á Pesca de Baixura e Marisqueo. Confraría de Pescadores de Celeiro, Rúa do
12 Porto 1, 27863 Viveiro, Lugo, Spain

13 ⁴Asistencia Técnica á Pesca de Baixura e Marisqueo. Confraría de Pescadores de O Barqueiro, Rúa
14 Alfredo Dovalé Álvarez s/n, 15337 Porto de O Barqueiro, Mañón, A Coruña, Spain

15 ⁵Asistencia Técnica á Pesca de Baixura e Marisqueo. Confraría de Pescadores de O Vicedo, Peirao
16 36, 27860 O Vicedo, Lugo, Spain

17 ⁶Asistencia Técnica á Pesca de Baixura e Marisqueo. Confraría de Pescadores de Espasante, Xuncal
18 s/n, 15339 Espasante, Ortigueira, A Coruña, Spain

19 ⁷Universidad de Vigo-Lagoas Marcosende, 36200, Vigo, Spain

20 ⁸Asistencia Técnica á Pesca de Baixura e Marisqueo. Agrupación de Mariscadores San Cosme, Rúa
21 Vilar s/n, 27790 Barreiros, Lugo, Spain

22 ⁹Asistencia Técnica á Pesca de Baixura e Marisqueo. Confraría de Pescadores de Ribadeo, Peirao
23 de Porcillán s/n, 27700 Ribadeo, Lugo, Spain

24 ¹⁰Asistencia Técnica á Pesca de Baixura e Marisqueo. Confraría de Pescadores Nuestra Señora del
25 Carmen, Avda. Manuel Fraga Iribarne 8-10, 15360 Cariño, A Coruña, Spain

26 *Corresponding author: jose.daniel.cerdeira.arias@xunta.gal

27

28 **ABSTRACT**

29 Intertidal shellfish banks in estuarine areas are influenced by a wide variety of environmental
30 conditions, including the physical and chemical characteristic of the water that floods the grounds.
31 In this study we carry out a cross-comparison of the hydrographic characteristics and nutrient
32 fertilization patterns of the waters that laps the shellfish grounds of a group of five drowned valleys
33 collectively known as “Rías Altas”, located in the western Cantabrian coast (NW Iberian Peninsula).
34 This region is affected by coastal upwelling from June to August resulting in a water exchange
35 between the embayments and the shelf varying between 31.5 and $220.5 \text{ m}^3 \text{ s}^{-1}$. The fresh water
36 discharge followed a seasonal cycle too, with maxima in winter and minima in summer, and long-
37 term average flow rates ranging from $5.9 \text{ m}^3 \text{ s}^{-1}$ to $22.2 \text{ m}^3 \text{ s}^{-1}$. Significant differences were
38 observed among the five embayments with regard to temperature and salinity and also with
39 inorganic nutrients, chlorophyll *a* and particulate organic matter concentrations in the continental
40 waters.

41

42 **Highlights:**

- 43 • Continental waters dictate the different fertilisation patterns among the Rías Altas
- 44 • Extension and geomorphology of the drainage basins explains continental nutrient inputs
- 45 • Continental nutrient inputs control organic matter concentrations in the inner rías
- 46 • Production in the inner rías is extremely P-limited

47

48 **Keywords:** continental runoff, coastal winds, temperature, salinity, inorganic nutrients, chlorophyll
49 *a*, particulate organic matter, shellfish grounds, Rías Altas, NW Iberian Peninsula

50

51 **1. Introduction**

52 Coastal ecosystems are characterised by the overriding interactions between atmospheric,
53 terrestrial, marine, and freshwater environments, which result in a remarkable variability and
54 biological productivity (Burke et al., 2001; Wollast, 1998), and by their accessibility. Accordingly,
55 coastal zones have been epicentres of human activity for millennia, and nowadays they are more
56 densely populated than the countries' interior (Neumann et al., 2015). Coastal ecosystems provide a
57 wide assortment of goods and services including the production of fish, shellfish, and seaweed for
58 human consumption (Burke et al., 2001). Continuous exploitation of these living resources by a
59 growing human population has caused numerous disturbances and collapses along its history
60 (Jackson et al., 2001).

61 Marine shellfish species have been collected for centuries (Ramos et al., 2011) mostly in
62 estuaries and sandy beaches. Overexploitation has resulted in severe depletions in past times though
63 being more widespread during the current industrial period (Lotze et al., 2006). Among the shellfish
64 species, bivalves are of major socioeconomic importance for coastal communities. Despite the small
65 contribution of the four main groups of bivalves (scallops, oysters, mussels and clams) to the global
66 capture production (1.6% in 2015; FAO, 2016), they produce large profits due to their generally
67 high unitary price (Gosling, 2015). Spain is a major bivalve producer from both aquaculture and
68 wild origin (Pawiro, 2010), with the Northwest coast a main area for clams, common cockle or
69 mussel extraction (Labarta et al., 2004; Surís-Regueiro and Santiago, 2014). This region is
70 characterized by the presence of numerous coastal embayments. More specifically, in the western
71 Cantabrian coast (NW Iberian Peninsula) there are a group of five drowned valleys collectively
72 known as “Rías Altas” (Fig. 1), which were flooded during the last Flandrian transgression (Zazo et
73 al., 1994). Currently, the Rías Altas are partially to well-mixed embayments. They consist of an
74 external part, deeper, wider and freely connected to the adjacent continental shelf, with prevailing
75 oceanic characteristics, and an internal part, which is partially enclosed with well-developed beach

76 barriers. Comparatively, the internal part is shallower and narrower, and receives most of the
77 continental runoff, therefore exhibiting prevailing estuarine characteristics (Evans and Prego, 2003).
78 It is in the internal part of these embayments where the intertidal shellfish grounds traditionally
79 exploited by the local shellfish harvesters are located (Arnaiz et al, 2005). The semi-diurnal tidal
80 regime of the area, with a tidal range from 1 to 4 m, covers and uncovers the grounds twice a day
81 (Portnoy and Giblin, 1997; Vranken and Oenema, 1990). Here, bivalves are basically collected on
82 foot in the sandbanks providing a considerable amount of employment and income typically to
83 women, as in other parts of Europe (Frangoudes et al., 2008; Surís-Regueiro and Santiago, 2014).

84 As for most sedentary invertebrates, the distribution and abundance of bivalve populations are
85 influenced by a wide variety of environmental drivers, including the physical and chemical
86 characteristic of the water that floods the grounds, the substrate type, the food availability or the
87 occurrence of predators. All these drivers act in synergy affecting almost every biological and
88 physiological aspect of the species and shape the population dynamics (e.g. Beukema and Dekker,
89 2014). This study focuses on the hydrographic characteristics of the waters that flood the grounds of
90 the main species of infaunal bivalves harvested in the study area: grooved carpet shell (*Ruditapes*
91 *decussatus*), pullet carpet shell (*Venerupis senegalensis*), Japanese carpet shell (*Ruditapes*
92 *philippinarum*), wedge shell (*Donax trunculus*), common cockle (*Cerastoderma edulis*) and razor
93 shell (*Solen marginatus*).

94 Our understanding of the hydrography of the Galician Rías Altas is still limited with the first
95 descriptions being very recent (e.g. Ospina-Álvarez et al., 2010; 2014). A comparative study of the
96 five embayments based on simultaneous repeated hydrographic surveys over an annual cycle is still
97 lacking. This kind of study is required to properly compare their hydrography and nutrient
98 fertilization patterns in view of the importance of the environmental conditions for the long-
99 standing maintenance and exploitation of the bivalve resources inhabiting the internal part of the
100 Rías Altas. In this regard, the Rías Altas constitute a geographical area with common climatological

101 and oceanographic characteristics that makes them suitable for a comparative study. Additionally,
102 they support a relatively low urban pressure, with a population density of 49.48 ind km⁻² in 2008,
103 when this study was conducted, which increases during summer holidays. Urban areas represent
104 13.3% of the surface area and are surrounded by 66.9 % of forestland, 18.6 % of meadows and 1.2 %
105 of farmland in the same year (data taken from the website of the Instituto Galego de Estatística:
106 <https://www.ige.eu>). The waters of the Rías Altas do not seem to be particularly affected by human
107 activities, offering a unique opportunity to study nutrients and organic matter inputs in a relatively
108 unpolluted region (Bode et al., 2011a; Álvarez-Vázquez et al., 2016). Within this framework, our
109 objective was to characterize and compare the ample shellfish grounds of the five Rías Altas in
110 terms of temperature, salinity, inorganic nutrients, chlorophyll and suspended organic matter in
111 order to assess the differential importance of marine and continental nutrient sources in the
112 fertilization of these embayments.

113

114 **2. Material and methods**

115 *2.1. Study area*

116 The embayments of Ortigueira, O Barqueiro, Viveiro, Foz and Ribadeo are located in the
117 western Cantabrian coast (NW Spain, Fig. 1). According to the classification of Köppen-Geiger, the
118 climate of this area is oceanic, temperate and humid, with an average air temperature of 13.1 °C and
119 an average annual rainfall of 1370 mm (Peel et al., 2007; Hess, 2014). Vigorous mixing of
120 continental and marine waters, ample semidiurnal tides (1–4 m), and coastal winds dictate the
121 hydrography and dynamics of these embayments that, in turn, condition the topography and nutrient
122 fertilization patterns of their extensive bivalve sandbanks.

123 Production of organic matter for bivalve filter feeders in the Rías Altas ultimately rests on
124 marine phytoplankton. Dinoflagellates, small flagellates and Cryptophyceans are particularly
125 abundant in early spring and summer whereas diatoms dominate in late spring and autumn (Ospina-

126 Álvarez et al., 2014). According to these authors, small flagellates, with an average concentration of
127 around 10^3 cells mL^{-1} , represented 85% of the total phytoplankton abundance, while larger
128 phytoplankton is composed of diatoms (12%, about 10^2 cells mL^{-1}) and dinoflagellates (3%, about
129 10 cells mL^{-1}). Currently, there are no studies reporting harmful algal bloom (HAB) episodes in the
130 Rías Altas (Ospina-Álvarez et al., 2010), however shellfish grounds are frequently closed to taking
131 out because of HABs. Microzooplankton (40-200 μm) abundance is high (12000 ind m^{-3}) and
132 dominated by larvae of copepods (nauplii), bivalves and gastropods. Mesozooplankton (>200 μm)
133 is also characterised by high numbers (5000 ind m^{-3}), with copepods and appendicularia as the
134 dominant groups (Ospina-Álvarez et al., 2010).

135 The circulation and composition of the water in the banks depends on: i) the geology of the area,
136 both tectonic and sedimentary; ii) the volume of seawater that enters or leaves the embayment at
137 each ebb or flood tide; iii) the volume of fresh water discharged by the rivers; and iv) the intensity
138 and direction of the coastal winds.

139 From the tectonic point of view, these embayments were collectively classified as Rías Altas
140 (Torre-Enciso, 1958). They fall within two different geological domains, the “Cabo Ortegal”
141 allochthonous complex and the “Ollo de Sapo” autochthonous domain, together with the contours
142 of influence of gneiss and quartzite, as well as the influence of the complexes slabs that dominate
143 the eastern part of the Galician Cantabrian range (Bernárdez et al., 2012; 2017; Prego et al., 2012).

144 Continental shelf surface waters and the upper layer of the Eastern North Atlantic Central Water
145 (ENACW) are the marine waters that enter the Rías Altas. ENACW consist of two branches
146 according to their origin: subpolar ENACW (ENACWp), colder than about 13 °C and formed north
147 of 43° N by winter cooling and deep convection, and subtropical ENACW (ENACWt), warmer than
148 about 13 °C and formed south of 43° N (McCartney and Talley, 1982; Ríos et al., 1992).

149 With regards to continental waters, the rivers that discharge in the Rías Altas are short and,
150 therefore, characterized by relatively low flows, according to the classification of Meybeck et al.

(1996). The drainage basins of the main rivers vary between 127 km² for River Mera that flows into the Ría de Ortigueira and 819 km² for River Eo that flows into the Ría de Ribadeo (Fig. 1; Table 1). River data were taken from the network of gauging stations operated by the regional agency Augas de Galicia and downloaded from the Spanish Ministry of Agriculture and Fisheries (<http://www.mapama.gob.es/es/>, see Table 1 for station information). River discharges (R) were normalised to the total catchment area (C_t) of each river from the river discharges (R_g) and catchment area (C_g) at the gauging station applying the Horton's law (Strahler, 1963):

$$R = R_g \cdot C_t / C_g \quad [1]$$

The prevailing wind regime in this area is characterised by north-easterly winds from March–April to September–October, while south-westerly winds predominate during the rest of the year (Wooster et al., 1976; Álvarez-Salgado et al., 2002). ENACWp is the dominant water mass in subsurface layers off the Rías Altas (Fraga 1981; Llope et al., 2006), particularly during the spring and summer, when the prevailing north-easterly winds promote the upwelling of this water mass and its subsequent entry into the embayments. Conversely, during the autumn and winter, the prevailing south-westerly winds boosts the Iberian Poleward Current (IPC) that transports ENACWt to the continental shelf off the Rías Altas and promote downwelling on the shelf that affects the circulation patterns of these embayments (Ospina-Álvarez et al., 2010). Coastal wind data, as well as the corresponding offshore Ekman transport (Q_Y) values in a 2° × 2° geostrophic cell centred at 43° N, 11° W (Fig. 1), were taken from the website of the Instituto Español de Oceanografía (<http://www.indicedeafloramiento.ieo.es>). Negative values of Q_Y indicate transport of the Ekman layer to the south (producing coastal downwelling), whereas positive values of Q_Y indicate transport of the Ekman layer to the north (producing coastal upwelling).

2.2. Sampling strategy

The shellfish grounds traditionally exploited in the Rías Altas (Arnaiz et al., 2005) were taken as

176 a reference to decide the location of the sampling sites. The sampling sites were positioned in the
177 centre or the most representative place of each shellfish bank area (Fig. S1). Overall, 64 sampling
178 sites (20 in Ortigueira, 15 in O Barqueiro, 10 in Viveiro, 9 in Foz, and 10 in Ribadeo) were visited
179 with monthly frequency from April 2008 to March 2009.

180 The surveys were performed on small boats at high tide coinciding with weeks of spring tides for
181 easy access to internal shellfish grounds. Water samples were collected with an acid washed
182 polyethylene bucket. At each sampling site, temperature and salinity of the water collected with the
183 bucket were immediately recorded with a portable multi-parameter probe YSI Environmental Pro
184 previously calibrated with a standard solution YSI 3169 of 50000 μS . Then, the water was
185 transferred to an acid washed 5L opaque container. Once in the laboratory, aliquots from the 5L
186 containers were fractionated in 100 mL Pyrex glass flasks for salinity determination that were kept
187 in the dark and in 50 mL polyethylene bottles for nutrient salts determination that were frozen at
188 -20°C . In addition, 150 mL of each sample were filtered through a Millipore GF/F filter of 25 mm
189 diameter. These filters were stored in 2 mL polyethylene vials and frozen at -20°C to analyse their
190 chlorophyll content. Furthermore, 300 mL were filtered through pre-combusted (450°C , 6h)
191 Whatman GF/F filters of 25 mm diameter. As in the previous case, the filters were stored in 2 mL
192 polyethylene vials and frozen at -20°C until analysing their content for organic carbon and nitrogen.
193 Chlorophyll and organic matter samples were filtered under low vacuum conditions (-0.2 atm) to
194 prevent cell breakdown. Before freezing, the filters for organic matter determination were vacuum
195 dried overnight in a desiccator.

196

197 2.3. *Analytical procedures*

198 2.3.1. *Salinity*

199 Salinity was determined with a PORTASAL salinometer at a constant temperature of $21.00 \pm$
200 0.01°C . The salinometer was installed in a room at $21.0 \pm 0.5^{\circ}\text{C}$, in which the temperature of the

201 samples were acclimatised before measurement. The conductivity readings were converted into
202 practical salinity scale values using the equation of UNESCO (1985). Salinity values obtained with
203 the salinometer were compared with the *in situ* measurements made with the multi-parameter probe
204 YSI Pro. An excellent agreement between the probe and the salinometer was found for samples in
205 which aliquots for determination of salinity were taken (origin intercept, n.s.; slope = 1.000 ± 0.001 ,
206 $R^2 = 0.999$, $p < 0.0001$).

207

208 2.3.2. *Nutrient salts*

209 Nutrient salts were determined simultaneously by automatic segmented flow analysis with
210 colorimetric detection using an Alpkem analyser. Ammonium was determined by the indophenol
211 blue method; nitrite by the azoic salt method; nitrate by reduction to nitrite in a copper/cadmium
212 column and subsequent determination as nitrite; and phosphate and silicate by the molybdate
213 reaction method. A detailed description of these methods can be found in Grasshoff et al. (1999).

214

215 2.3.3. *Chlorophyll a*

216 The chlorophyll *a* content was determined by the classical fluorimetric method of Yentsch and
217 Menzel (1963). After freezing at -20°C for 24h to promote the breakage of phytoplankton cells,
218 chlorophyll was extracted in 90% acetone for about 6 hours and, then, it was determined in a Turner
219 Designs fluorimeter. Adding 0.1N hydrochloric acid and measuring again allowed correction of the
220 signal due to phaeopigments.

221

222 2.3.4. *Particulate organic matter*

223 For the quantification of particulate organic carbon (POC) and nitrogen (PON) the material
224 collected onto pre-combusted GF/F filters was analysed on a Perkin Elmer 2400 CHN. The method
225 is based on the catalytic oxidation at 900°C of organic carbon to CO_2 and organic nitrogen to

226 molecular nitrogen (N₂), which are separated in a chromatographic column and detected by thermal
227 conductivity.

228

229 2.4. Statistical analyses

230 Average seasonal cycles of temperature and salinity for each embayment during the study period
231 were modelled by fitting a simple harmonic equation to the corresponding field data (Y):

$$232 \quad Y_{i,t} = A_0 + A_1 \times \sin\left(\frac{2 \times \pi \times t}{365} + \phi\right) \quad [2]$$

233 where Y is the salinity or temperature recorded at a site i , t is the day of the year (from 1 to 365), A_0
234 is the annual average of Y , A_1 is the amplitude of the seasonal cycle of Y , and ϕ is the phase which
235 has been used to calculate the day of the year when the value of Y coincides with the seasonal
236 maximum.

237 To properly model the seasonal cycles of nutrient salts, chlorophyll a , and particulate organic
238 carbon and nitrogen using a unique equation per embayment, it is necessary to take into account the
239 different impact that the mixing of marine and continental waters have at each sampling site within
240 the embayment. Thus, an additional term was added to Eq. 2 as follows:

$$241 \quad Y_{i,t} = A_0 + A_1 \times \sin\left(\frac{2 \times \pi \times t}{365} + \phi\right) + A_2 \times S_{i,t} \quad [3]$$

242 where S is the salinity measured at each site i and sampling day t and A_2 is the slope of the
243 relationship between the variable Y and salinity, i.e. the parameter that models the mixing between
244 continental and marine waters.

245 All treatment of data and analyses were performed with the software R (version 3.4.3, R Core
246 Team, 2017). Models were specifically fitted using Levenberg-Marquardt algorithm implemented in
247 the package ‘minpack.lm 1.2-1’ (Elzhov et al., 2016).

248

249 3. Results

250 3.1. Meteorology: coastal winds and continental runoff

251 The offshore Ekman transport (Q_Y) caused by the coastal wind blowing parallel to the northern
 252 coast of Galicia (Fig. 2A) follows a well-defined seasonal cycle, evolving from negative values at
 253 the beginning of the year to positive values in late spring and summer (upwelling season) and
 254 returning to negative values through the autumn and winter (Fig. 2B). In the long term, the 1967–
 255 2016 annual average [confidence limit] of Q_Y during the upwelling season in the study area was 35
 256 [14 to 56] $\text{m}^3 \text{s}^{-1} \text{km}^{-1}$ of coast. Considering this long-term average Q_Y and the wideness at the
 257 mouth of the Rías Altas (W , in km; Table 1), the water exchange between the embayments and the
 258 shelf ($Q_{OC} = Q_Y \cdot W$; Rosón et al., 1997; Álvarez-Salgado et al., 2000) would vary between 31.5
 259 and 220.5 $\text{m}^3 \text{s}^{-1}$, with an average of 111.3 $\text{m}^3 \text{s}^{-1}$ (Table 1).

260 Fresh water supply by the rivers (R ; Fig. 3A-E) also followed a seasonal cycle, with maxima in
 261 the winter months and minima in the summer months (Fig. 3F-J). Long-term average flow rates
 262 ranged from 5.9 $\text{m}^3 \text{s}^{-1}$ for River Mera to 22.2 $\text{m}^3 \text{s}^{-1}$ for River Eo (Table 1).

263 Knowledge of Q_{OC} and R allowed us to assess the relative importance of the oceanic flow during
 264 the upwelling season and the continental water flow that enters the Rías Altas. In general, Q_{OC} is
 265 about 10.4 times R , but varying between 1.4 and 23.7 (Table 1), with a trend to decrease from West
 266 (larger oceanic influence) to East (larger continental influence).

267

268 3.2. Hydrography: temperature and salinity

269 Table S1 summarizes the coefficients of Eq. 2 obtained for the water temperatures recorded in
 270 each ría. Predictions from the harmonic model correlated well with the response variable in each ría
 271 (with goodness of fit between 0.95 and 0.97, Fig. S2), independently of the shellfish ground where
 272 the samples were collected. Considering the annual average (A_0), it was found that the shellfish
 273 grounds of Ribadeo and Ortigueira were significantly ($p < 0.05$) colder than those of Viveiro and O
 274 Barqueiro, and these were significantly colder than those of Foz (Fig. 4A). Concerning the seasonal
 275 amplitude (A_1), Foz and Viveiro were characterised by larger amplitudes than Ribadeo, O Barqueiro

276 and Ortigueira (Fig. 4I). Finally, the phase (ϕ) indicated that maximum water temperatures were
277 reached by late July to early August, being a week earlier in the shellfish grounds of Foz and
278 Viveiro than in those of Ribadeo, O Barqueiro and Ortigueira (Fig. 4Q).

279 For the case of salinity, the goodness of fit of the harmonic model varied from 0.24 to 0.49
280 (Table S1 and Fig. S2). As for the case of water temperature, Eq. 2 does not account for the
281 geographical position of the shellfish grounds in each ría. Therefore, the low percentage of the
282 variability of salinity explained by Eq. 2 is due to the well-known fact that salinity is strongly
283 affected by the relative position of the shellfish grounds with respect to the continental and ocean
284 inputs. In any case, these simple harmonic models were statistically significant and provided
285 valuable information to compare among rías. The annual average salinity of the shellfish grounds of
286 Ribadeo, Foz and O Barqueiro were not significantly different, ($p > 0.05$) with values ranging from
287 32.1 to 32.7. However, the shellfish grounds of Viveiro were significantly fresher ($p < 0.05$) at 28.3
288 ± 0.7 , and those in Ortigueira were significantly saltier ($p < 0.05$) at 33.9 ± 0.2 (Fig. 4B). The
289 amplitudes of the seasonal cycles of salinity followed a similar pattern with Viveiro exhibiting
290 much higher amplitude (5.9 ± 1.0) than the shellfish grounds of the other embayments (1.5–2.1)
291 (Fig. 4J). The salinity maximum was found first in Ribadeo and Ortigueira (late July to early
292 August), and latter in the other embayments (late August to mid September) (Fig. 4R).

293

294 3.3. *Inorganic nutrients: inorganic nitrogen, phosphate and silicate*

295 Most of the dissolved inorganic nitrogen (DIN) in the waters that flood the shellfish grounds of
296 the Rías Altas is in the most oxidized form of nitrate, with an average (SD) proportion of 61%
297 (28%), followed by ammonium, with 29% (22%) and nitrite, with 10% (9%). This partition is
298 common to all the Rías Altas but Ortigueira, which presented a significantly lower ($p < 0.05$)
299 proportion of nitrate of 49.6% (28.8%) and higher proportion of ammonium of 38.9% (23.0%). In
300 the case of the nutrient salts, apart from the seasonal cycle of consumption-regeneration, it is also

301 important to consider the mixing of relatively nutrient-rich continental waters with relatively
 302 nutrient-poor oceanic waters. Hereafter we define the continental and marine end-members as the
 303 concentrations of inorganic and organic nutrients at salinity zero and 35.5, respectively. Predictions
 304 from the extended harmonic Eq. 3, which models both sources of variability, correlated well with
 305 the DIN concentration with goodness of fit ranging from 0.91 to 0.97 (Table S2 and Fig. S3). The
 306 independent term (A_0) of Eq. 3, representing the annual average concentration of DIN at salinity
 307 zero ($S = 0$), i.e. in the continental end-member, rose significantly ($p < 0.05$) from West (38 ± 1
 308 $\mu\text{mol kg}^{-1}$ at O Barqueiro) to East ($97 \pm 3 \mu\text{mol kg}^{-1}$ at Ribadeo). In Ortigueira, there was an
 309 increase to $45 \pm 2 \mu\text{mol kg}^{-1}$ that coincided with the levels observed in Viveiro (Fig. 4C). In
 310 comparison, the annual average concentration at the reference salinity for marine waters ($S = 35.5$),
 311 which can be simply obtained as $A_0 + A_2 \cdot S$, was around $2.59 \pm 0.81 \mu\text{mol kg}^{-1}$ for the five
 312 embayments (Table S2). Concerning the amplitude of the seasonal cycle (A_1) there were no
 313 significant differences between embayments except for Ribadeo, which presented an amplitude
 314 significantly larger than the others ($p < 0.05$) (Fig. 4K). Finally, with regard to the phase, there were
 315 no significant differences in the timing of the seasonal cycle of DIN between embayments with the
 316 maximum being around the first half of January and, therefore, the seasonal minimum located
 317 around the first half of July (Fig. 4S).

318 Goodness of fit of the predictions for phosphate from Eq. 3 ranged from 0.56 to 0.89 (Table S2
 319 and Fig. S3). The annual average concentration of phosphate in the continental end-member rose
 320 dramatically ($p < 0.05$) from $0.12 \pm 0.03 \mu\text{mol kg}^{-1}$ in O Barqueiro to $1.02 \pm 0.06 \mu\text{mol kg}^{-1}$ in
 321 Ribadeo. Again, a significant increase was observed in the westernmost Ría de Ortigueira (Fig. 4D).
 322 In comparison, there were not significant differences in the mean annual concentration of phosphate
 323 in the marine end-member, which was $0.18 \pm 0.04 \mu\text{mol kg}^{-1}$ for the five embayments (Table S2).
 324 The seasonal amplitude of phosphate was not particularly variable, ranging from $0.17 \pm 0.01 \mu\text{mol}$
 325 kg^{-1} in Foz to $0.10 \pm 0.01 \mu\text{mol kg}^{-1}$ in Viveiro (Fig. 4L). Concerning the phase, it is remarkable

326 that phosphate reached the maximum concentrations in Ribadeo and Viveiro in early January, being
327 significantly different ($p < 0.05$) from Foz and O Barqueiro, at the end of January and Ortigueira
328 was found to be between these two sets of values (Fig. 4T).

329 For the case of silicate, Eq. 3 explained the variability of this nutrient salt with correlations
330 ranging from 0.81 to 0.98 (Table S2 and Fig. S3). The annual average concentration in the
331 continental end-member increased significantly from West to East. However, the maximum
332 concentration of $118 \pm 2 \mu\text{mol kg}^{-1}$ was found in the westernmost Ría de Ortigueira (Fig. 4E). The
333 average annual concentration of silicate in the marine end-member was $4.1 \pm 2.6 \mu\text{mol kg}^{-1}$ for all
334 the Rías Altas (Table S2). Concerning the seasonal amplitude, Ribadeo and Viveiro presented larger
335 amplitudes than O Barqueiro and Ortigueira ($p < 0.05$). Foz was between these two groups (Fig.
336 4M). Regarding the timing of the seasonal maximum of silicate, it occurred between late December
337 in Foz and early February in O Barqueiro, however, in Ortigueira the maximum was in late October
338 (Fig. 4U).

339

340 3.4. Organic nutrients, chlorophyll *a* and particulate organic matter

341 Table S3 shows the coefficients obtained when fitting the harmonic Eq. 3 to the chlorophyll *a*
342 data. This model moderately explained the spatial-seasonal variability of this variable (goodness of
343 fit from 0.3 to 0.61, Table S3 and Fig. S4). The annual average concentration of chlorophyll *a* for S
344 $= 0$ increased significantly ($p < 0.05$) from West (O Barqueiro) to the East (Ribadeo), and in
345 Ortigueira there was an increase to the same level observed in Ribadeo (Fig. 4F). On the other hand,
346 there were not significant differences in the annual average concentration of chlorophyll *a* for $S =$
347 35.5 , which was $2.16 \pm 0.37 \mu\text{mol L}^{-1}$ (Table S3). Concerning the seasonal amplitude, it was
348 significantly higher in Ribadeo ($p < 0.05$) than in the other embayments (Fig. 4N). Regarding the
349 timing of the seasonal cycle, maximum chlorophyll *a* levels in O Barqueiro were observed in
350 January, while in Foz and Ribadeo it was in April and June, respectively, being significantly

351 different ($p < 0.05$) compared to Viveiro and Ortigueira, which occurred in late July to early August
352 (Fig. 4V).

353 The behaviour of particulate organic carbon (POC) was roughly parallel to chlorophyll *a*, with
354 the model moderately explaining the variability of this variable (goodness of fit from 0.28 to 0.6,
355 Table S3 and Fig. S4). The annual average of POC increased significantly ($p < 0.05$) from West (O
356 Barqueiro) to East (Ribadeo), and in Ortigueira there was an increase to levels not significantly
357 different from those observed in Ribadeo (Table S3, Fig. 4G). The seasonal amplitude was
358 significantly larger in O Barqueiro ($p < 0.05$) than in the other embayments (Fig. 4O). Regarding
359 the timing of the seasonal cycle, O Barqueiro had maximum POC in February, while in Ribadeo
360 occurred in June, being significantly different ($p < 0.05$) as compared with Foz, Viveiro and
361 Ortigueira, with their respective maxima by October–November (Fig. 4W).

362 Finally, regarding the C/N ratio of POM the model moderately explained the variability of this
363 variable (goodness of fit from 0.45 to 0.91, Table S3 and Fig. S4). Regarding the annual average
364 there were no significant differences in both continental and marine end-members among
365 embayments, except for Viveiro, where the C/N ratio of the continental end-member was
366 significantly ($p < 0.05$) higher, and Ortigueira, where it was significantly ($p < 0.05$) lower (Table S3,
367 Fig. 4H). The seasonal amplitude of the C/N ratio dropped significantly ($p < 0.05$) from Viveiro
368 (2.7 ± 0.2 mol C/mol N) to Ortigueira (1.1 ± 0.1 mol C/mol N): Viveiro > O Barqueiro > Foz >
369 Ribadeo > Ortigueira (Fig. 4P). The timing of the seasonal cycle indicated that all embayments
370 reached their C/N ratio maxima in January (Fig. 4X).

371

372 **4. Discussion**

373 *4.1. The Rías Altas in the context of the NW Iberian upwelling system*

374 The Galician coast, from River Miño to River Eo, in the NW corner of the Iberian Peninsula (Fig.
375 1), presents remarkable oceanographic and orographic features. From the oceanographic point of

view it is placed at the northern boundary of the coastal upwelling system associated to the Canary current, i.e. one of the four large marine upwelling ecosystems of the world ocean (Wooster et al., 1976; Arístegui et al., 2009). From the orographic point of view, there are two features that should be emphasized, coastal orientation and orography. There is an abrupt change in the orientation of the coast: between River Miño and Cape Fisterra (western coast) is oriented meridionally, between capes Fisterra and Prior (north western coast) is oriented obliquely, and between Cape Prior and River Eo (northern coast) is oriented longitudinally (Fig. 1). This change in the orientation of the coast has important implications for coastal upwelling: whereas northerly winds produce upwelling in the western coast, easterly winds do it in the northern coast, and north easterly winds in the north western coast (Álvarez et al., 2010b; 2011). Long-term average [confidence intervals] values of the offshore Ekman transport during the upwelling season 1967–2016 are 295 [277 to 313] $\text{m}^3 \text{s}^{-1} \text{km}^{-1}$ for the western coast (April–September), 216 [192 to 241] $\text{m}^3 \text{s}^{-1} \text{km}^{-1}$ for the north western coast (May–August), and 35 [14 to 56] $\text{m}^3 \text{s}^{-1} \text{km}^{-1}$ for the northern coast (June–August). Therefore, the interaction between the direction of coastal winds and the orientation of the coast has a direct effect on the exposure to upwelling of the western (the most exposed), north western, and northern (the least exposed) coasts. In fact, the western coast is 8.4 times ($= 295 / 35$) more exposed to coastal upwelling than the northern coast during the upwelling season, which is 6 months long in the western coast and just 3 months long in the northern coast (Álvarez et al., 2010b).

On the other side, the Galician coast is characterised by an intricate orography, being occupied by sixteen coastal embayments of variable size and continental runoff exposure (Torre-Enciso, 1958; Fraga, 1996; Prego et al., 1999). The coastal embayments in the western coast, collectively known as Rías Baixas, are large ($2.47\text{--}4.34 \text{ km}^3$), wide ($125\text{--}230 \text{ km}^2$) and with elevated river discharge ($20\text{--}96 \text{ m}^3 \text{s}^{-1}$; Fraga, 1996; Prego et al., 1999; Álvarez-Salgado et al., 2011). In contrast, the embayments in the northern coast, the Rías Altas, are comparatively much smaller ($< 0.4 \text{ km}^3$, $3\text{--}26 \text{ km}^2$) and with lower river discharge ($6\text{--}22 \text{ m}^3 \text{s}^{-1}$; Table 1). The embayments of the north western

coast, the Rías Centrais, present intermediate characteristics, with volumes ranging from 0.1 to 0.7 km³, areas between 17 and 52 km², and river flows between 7 and 31 m³ s⁻¹ (Fraga, 1996; Prego et al., 1999; Álvarez-Salgado et al., 2011). The relationship between the annual average river discharge (ΣR , in m³) and the volume (V , in m³) of the embayment ($\Sigma R/V$, dimensionless) is > 4 for the case of the Rías Altas, except for Viveiro (Table 1). Comparatively, it is between 0.8 and 2.4 for the Rías Centrais and < 0.7 for the Rías Baixas, which indicates that continental inputs play a more important role in the hydrology of the Rías Altas. Multiplying the offshore Ekman transport by the wideness of the open end of the embayment yields average Q_{OC} values of 2170 m³ s⁻¹ for the Rías Baixas, 625 m³ s⁻¹ for the Rías Centrais (Fraga 1996; Álvarez-Salgado et al., 2011) and just 111.3 m³ s⁻¹ for the Rías Altas (Table 1). Comparison of these fluxes integrated over the 6-month upwelling season ($\Sigma Q_{OC} = 6 \cdot Q_{OC}$) with the volume of the embayments (V) leads to average $\Sigma Q_{OC}/V$ values of 10 for the Rías Baixas, 32 for the Rías Centrais and 26 for the Rías Altas (Table 1). This means that whereas coastal upwelling contributes to renew the Rías Baixas 10 times during the upwelling season, the Rías Centrais and Altas renew about 30 times over the same period. Note, that despite the upwelling season in the north western coast extending for 4 months and in the northern coast for 3 months, we have integrated Q_{OC} over 6 months in the three areas to allow direct comparison of renewal rates. Therefore, although the exposure of the northern coast to upwelling is almost one tenth than in the western coast (offshore Ekman transport of 35 *versus* 295 m³ s⁻¹ km⁻¹), the impact of coastal upwelling on the renewal and nutrient fertilisation of the Rías Altas is almost 3-fold more than in the Rías Baixas ($\Sigma Q_{OC}/V$ of 26 *versus* 10 times).

In summary, given their relatively small size, the hydrology and nutrient fertilization of the Rías Altas are much more sensitive than the Rías Baixas to both coastal upwelling and continental runoff.

4.2. Nutrient fertilisation patterns

The harmonic model used in this work (Eq. 3) has revealed that the differences in nutrient

426 fertilisation patterns among the five Rías Altas are essentially associated with differences in the
427 concentrations of the continental end-members (Fig. 4C-E, Table S2). It should be noted that our
428 sampling was restricted to the inner part of the embayments, where the shellfish banks are placed.
429 In the outer part, the relationship of nutrient salts with salinity is generally weak, indicating low
430 river influence (Bode et al., 2011a; Ospina-Álvarez et al., 2014).

431 Our continental end-members, obtained by extrapolation to $S = 0$, are not directly comparable
432 with the concentrations measured upstream in the rivers, because the latter do not account for the
433 processes occurring downstream at the freshwater-seawater interface, FSI (Regnier et al., 1997).
434 The extension and the topography of the drainage basin, the rainfall regime, the nature of the soil
435 and the different land uses determines the inorganic nutrient loads of a river stream (Meybeck and
436 Helmer, 1989; Esser and Kohlmaier, 1991; Mulholland, 1997). For the case of DIN, the
437 concentration of the continental end-member ranges from $38 \mu\text{mol kg}^{-1}$ for River Sor (O Barqueiro)
438 to $97 \mu\text{mol kg}^{-1}$ for River Eo (Ribadeo) (Fig. 4C; Table S2). The fact that the flow of River Sor
439 ($11.0 \text{ m}^3 \text{ s}^{-1}$; Table 1) is about half than of River Eo ($22.2 \text{ m}^3 \text{ s}^{-1}$) suggests a significant flushing
440 effect, which is characteristic of basins where nutrients are dominantly of soil and plant origin
441 (Esser and Kohlmaier, 1991; Spitzy and Leenheer, 1991). Furthermore, Fig. 5A shows an excellent
442 relationship between DIN concentration of the continental end-member and the river catchment area,
443 reinforcing the postulation of the natural origin of riverine DIN in the Rías Altas (Álvarez-Vazquez
444 et al., 2016). Results obtained from stable isotopes also confirmed the natural origin of the DIN in
445 these embayments (Bode et al., 2011a).

446 For the case of phosphate, there is also a significant positive relationship between continental
447 end-members and catchment area (Fig. 5B), suggesting again a natural origin for the phosphate
448 discharged by the rivers of the Rías Altas. **It is remarkable that the phosphate concentration of the**
449 **continental end-member does not exceed $1 \mu\text{mol kg}^{-1}$.** In this sense, it is known that the phosphate
450 concentrations rarely exceed this value in estuaries because of the formation of iron phosphate

451 precipitates (Froelich, 1988).

452 Finally, for the case of silicate, the continental end-members, also exhibit a significant linear
453 relationship with the catchment area except for the case of the Ría de Ortigueira (Fig. 5C). The
454 rivers draining in this embayment present more than twice the expected concentration at $S = 0$
455 according to the size of their catchment area. Ospina-Álvarez et al. (2010; 2014) and Bode et al.
456 (2011a) also obtained remarkably higher concentrations of silicate in River Mera and Lourido
457 stream (Ortigueira) than in the rivers draining the other Rías Altas. The reason behind this marked
458 difference seems to be the contrasting sedimentary and tectonic composition of the Ría de
459 Ortigueira, affected by the Cabo Ortegal allochthonous complex and the Ollo de Sapo
460 autochthonous domain (Prego et al., 2012; Bernárdez et al., 2017).

461 DIN and phosphate levels found in the continental end-members of the Rías Altas are of the
462 same order than the concentrations extrapolated to $S = 0$ in the Rías Baixas (Pérez et al., 1992) but
463 generally somewhat higher than the concentrations measured upstream in the rivers (Pérez et al.
464 1992; Gago et al., 2005). This difference points to nutrient enrichment at the FSI. In general, DIN
465 and phosphate in the rivers that drain in the Galician rías are within the average values proposed by
466 Meybeck (1982) for unpolluted rivers. River Mero, in the Ría de A Coruña, with a catchment area
467 of 345 km² and a DIN concentration $> 200 \mu\text{mol kg}^{-1}$ (Bode et al., 2017) is an exception.
468 Furthermore, concentrations of DIN and phosphate are more than one order of magnitude higher in
469 the rivers of the adjacent Cantabrian coast, with comparable drainage basins (Prego and Vergara,
470 1998).

471 The average molar N/P ratio of inorganic nutrients in the continental end-member was 135 ± 104 ,
472 about twice the value obtained in the rivers of the Rías Baixas (Gago et al., 2005) and almost 10-
473 fold the Redfield's value of 16, characteristic of aquatic plants and phytoplankton (Redfield et al.,
474 1963; Anderson, 1995), pointing to P-limitation. Although P-limitation is characteristic of most
475 continental aquatic ecosystems (Turner et al., 2003), our numbers indicate that the rivers of the Rías

476 Altas are extremely P-limited, with the most extreme case being River Sor (O Barqueiro), with a
477 molar N/P ratio of 315 ± 24 .

478 Excluding the Ría de Ortigueira, the continental end-members of the Rías Altas transport silicate
479 concentrations that are about half of those found by Meybeck and Helmer (1989) in freshwater
480 streams draining granite rocks. However, the silicate specific flux of these basins, $50\text{--}70 \text{ mmol m}^{-2}$
481 y^{-1} , is about twice the expected value from the increase in silicate specific flux with decreasing
482 latitude in Northern hemisphere major rivers (Guo et al., 2004). Therefore, the relatively low
483 concentrations of silicate are more related to the small size of the drainage basins than to the
484 mineral composition of the soils. In the particular case of the Ría de Ortigueira, the silicate specific
485 flux of the continental end-member is much higher, $172 \text{ mmol m}^{-2} \text{y}^{-1}$, because of the already
486 mentioned particular sedimentary and tectonic characteristics of this embayment (Prego et al., 2012;
487 Bernárdez et al., 2017).

488 Concerning the average nutrient concentrations in the marine end-member, obtained by
489 extrapolation to $S = 35.5$, the resulting values ($2.59 \pm 0.81 \text{ } \mu\text{mol kg}^{-1}$ for DIN, $0.18 \pm 0.04 \text{ } \mu\text{mol kg}^{-1}$
490 1 for phosphate and $4.1 \pm 2.6 \text{ } \mu\text{mol kg}^{-1}$ for silicate) are around the average concentrations found in
491 the surface layer of the inner shelf / outer rías of the western (Nogueira et al., 1997), north western
492 (Casas et al., 1997; 1999) and northern coast (Bode et al., 2011; Ospina-Álvarez et al., 2014). It
493 should be noted that during coastal upwelling, oceanic ENACW upwells over the continental shelf
494 off the Rías Altas (Ospina-Álvarez et al., 2010). However, the marine end-member that enters these
495 embayments consists of this upwelled ENACW strongly modified by mixing with the resident
496 water over the shelf, therefore presenting lower nutrient level than the pure ENACW that penetrates
497 in the rías of the western coast (Bode et al., 2011a; Prego et al., 2012).

498 It is remarkable that the molar N/P ratio of the marine end-member is 14.5 ± 7.6 , i.e. close to the
499 canonical Redfield's ratio of 16. Furthermore, the average molar N/P ratio of the amplitude of the
500 seasonal cycles of DIN and phosphate (A_1 term in Eq. 3), which would represent the N/P ratio of the

501 net seasonal consumption/regeneration of nutrients in these embayments, is 35 ± 13 , ranging from
502 23 ± 3 in Ortigueira (the less P-limited) to 45 ± 12 in Viveiro (the most P-limited).

503

504 4.3. *Suspended food available for filter feeders*

505 Although the goodness of fit of the harmonic model (Eq. 3) applied to chlorophyll *a* and
506 particulate organic matter are relatively low (Table S3), the coefficients are significant and provide
507 valuable information that can be directly compared with the information provided by the inorganic
508 nutrients.

509 The average concentrations of Chl *a* and POC in the continental end-member cannot be
510 interpreted as the concentrations upstream in the rivers. Mass mortality of freshwater plankton
511 occurs at the FSI and marine plankton dominates downstream (Jackson et al., 1978). Therefore,
512 these end-member values should be understood as potential concentrations reached from the
513 utilisation of the inorganic nutrients generated at the FSI. The scarce measurements done in the
514 rivers of the Rías Altas indicate that Chl *a* ranges from 0.4 to $1.0 \mu\text{g L}^{-1}$ (Ospina-Álvarez et al.,
515 2010). Comparatively, our end-member concentrations cover a wider range, from 0.6 to $7.0 \mu\text{g L}^{-1}$
516 (Table S3). The same difference between river concentrations and continental end-member
517 estimates is also observed for POC. In the rivers, average POC ranges from 16 to $31 \mu\text{mol L}^{-1}$ with
518 a C/N molar ratio between 10 and 30 (Bernárdez et al., 2017). Conversely, the POC values
519 extrapolated to $S = 0$ were considerably higher, ranging from 40 to $124 \mu\text{mol L}^{-1}$ and the
520 corresponding C/N molar ratios were lower, from 5 to 13 (Fig. 4F-H; Table S3). These results are
521 coherent with the observation that high Chl *a* concentrations are generally found in the innermost
522 zone of the Rías Altas, where the river flow is the main nutrient source (Ospina-Álvarez et al., 2010;
523 Bode et al., 2011a). In this regard, the differences observed in the Chl *a* and POC of the continental
524 end-members of each embayment are related with the nutrient concentrations in these end-members.
525 Thus, the lowest Chl *a* and POC values corresponded to O Barqueiro and Viveiro, which were the

embayments presenting the lowest inorganic nutrients concentrations, particularly of the limiting nutrient, phosphate (Fig. 4G). Positive linear relationships were observed between phosphate and POC continental end-members ($R^2 = 0.97$, $p = 0.002$, $n = 5$).

Average Chl *a* and POC levels in the marine end-member ($S = 35.5$), $2.16 \pm 0.37 \mu\text{g L}^{-1}$ of Chl *a* and $35.3 \pm 6.2 \mu\text{mol L}^{-1}$ of C, do not differ significantly among embayments. For comparison, the annual average Chl *a* concentration in the outer part of the Ría de O Barqueiro during an annual cycle was $0.7 \mu\text{g L}^{-1}$ (Ospina-Álvarez et al., 2014). Therefore, the marine waters flooding the shellfish banks located in the innermost part of the Rías Altas, have 3-fold the Chl *a* levels reported by Ospina-Alvarez et al. (2014). Long-term annual average surface Chl *a* values are $> 1.5 \mu\text{g L}^{-1}$ in the middle-outer side of the embayments of the north western coast (Bode et al., 2011b) and $> 3 \mu\text{g L}^{-1}$ in the embayments of the western coast (Nogueira et al., 1997; Bode et al., 2011b). Although measurements of POC in the Rías Altas are very scarce, the existing numbers indicate that the concentrations increased from about $5 \mu\text{mol L}^{-1}$ in the outer part to $15\text{--}30 \mu\text{mol L}^{-1}$ in the innermost reaches of the embayments (Bode et al., 2011a), in agreement with the trend already observed in Chl *a*. For comparison, annual average POC in the central segment of the Ría de Vigo, in the western coast, is about $30 \mu\text{mol L}^{-1}$ (Doval et al., 1997; Nieto-Cid et al., 2005).

Finally, the C/N molar ratio of particulate organic matter can be used as an indicator of the nutritional quality of the suspended material fed by the bivalves. A C/N molar ratio of 6.7 is characteristic of marine phytoplankton growing under nutrient replete conditions (Redfield et al., 1963; Anderson, 1995). This C/N ratio corresponds with a biochemical composition of 45.1% proteins, 24.4% carbohydrates, 16.5% lipids, 12% phosphorus compounds and 2% pigments (Fraga et al., 1998). The C/N molar ratio of the POM in the marine water end-member that floods the shellfish grounds of the Rías Altas was 9.2 ± 0.4 . This ratio was significantly above the canonical Redfield's ratio, suggesting a lower proportion of N-containing compounds as the proteins and nucleic acids. For comparison, the annual average C/N molar ratio in surface waters of the Ría de

551 Vigo and the adjacent shelf is about 7 (Doval et al., 1997; Álvarez-Salgado et al., 2006).

552

553 **5. Conclusions**

554 The hydrography of the Rías Altas is dictated by coastal winds and continental runoff, showing a
555 larger oceanic influence in the west and continental influence in the east. Whereas the
556 concentrations of inorganic nutrients, chlorophyll *a* and organic matter in the marine waters that
557 flood the shellfish grounds are the same in the five embayments with significant differences
558 observed in continental waters. These differences are essentially related to the differential extension
559 and geomorphology of the drainage basins. Particularly, the concentration of silicate in continental
560 waters found in the westernmost Ría de Ortigueira, more than twice than expected, seems to be due
561 to the contrasting sedimentary and tectonic composition of the Ría de Ortigueira, affected by the
562 Cabo Ortegal allochthonous complex and the Ollo de Sapo autochthonous domain. Phosphate is the
563 limiting nutrient in continental waters, dictating the concentration of chlorophyll *a* and organic
564 matter in the inner reaches of the estuaries.

565

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771 **Figure captions**

772 Fig. 1. Map of the study area showing the location of the five Rías Altas (see Table 1 for physical
773 descriptions and Fig. S1 for the detailed location of the sampling sites in each ría). The cross
774 indicates the 43° N 11° W cell from where upwelling intensity was calculated.

775

776 Fig. 2. Daily upwelling index (Q_Y , in $\text{m}^3 \text{s}^{-1} \text{km}^{-1}$) from 2008 to 2010 (A) and average ($\pm 95\%$ CI)
777 seasonal cycle from 1967 to 2009 (B). Inverted triangles in A indicate the sampling dates.

778

779 Fig. 3. Trends in normalized runoff (R , in $\text{m}^3 \text{s}^{-1}$) during the sampling period for each river (A-E)
780 and long-term average ($\pm 95\%$ CI) seasonal cycles (F-J). Inverted triangles indicate the sampling
781 dates.

782

783 Fig. 4. Distribution of average values (A-H), amplitude (I-P) and phase (Q-X), i.e. parameters A_0 , A_1 ,
784 and ϕ of Eq. 2 and 3, for each variable studied across the five Rías Altas. Error bars indicate 95%
785 confidence intervals. Numerical results are shown in Tables S1 to S3 and data are shown in Fig. S2
786 to S3.

787

788 Fig. 5. Relationship between river catchment area and freshwater end-member nitrate (A),
789 phosphate (B) and silicate (C). Lines show linear regression fits in panels (A) and (C), and a 3-
790 parameter asymptotic exponential model in panel (B). Note that Ortigueira was excluded from the
791 regression model in panel (C).

792 **Tables**

793 Table 1. Physical characteristics of the Rías Altas (NW Spain) and their main rivers and gauge
 794 stations information. Q_{OC} is the volume of water exchanged between the ría and the adjacent shelf
 795 and R is the normalized river discharge (both in $m^3 s^{-1}$). $\sum R$ is the annual average normalized river
 796 discharge in m^3 .

Ría	Ortigueira	O Barqueiro	Viveiro	Foz	Ribadeo
Length (km)	10	8	7	3	5
Outer wideness (km)	4.4	2.7	6.3	1.6	0.9
Maximum depth (m)	15	20	35	10	17
Average depth (m)	7.3	6.2	16	0.3	8.9
Area (km ²)	11	13	26.3	2.6	4.5
Volume (V, in 10 ⁶ m ³)	80	80	420	0.65	40
Q_{OC} (m ³ s ⁻¹)	154	94.5	220.5	56	31.5
$\sum Q_{OC}/V$	30	19	8	NA ^a	12
River(s)	Mera, Baleo	Sor	Landro	Masma, Centiñó	Eo
Gauge station (code) ^b	1443	1440	1438	1431	1427
C_t (km ²)	265 ^c	202	270	304	819
C_g (km ²)	102 ^d	112	198	145	712
R^e (m ³ s ⁻¹)	12.3 ^f	11.0 ^g	9.3 ^h	9.4 ⁱ	22.2 ^j
$\sum R/V$	4.8	4.0	0.70	NA ^a	15
Q_{OC}/R	12.5	8.6	23.7	6.0	1.4

797 ^aNot calculated for Ría de Foz because this entire embayment is dried out every tidal cycle

798 ^bFrom: <http://www.mapama.gob.es/es/>

799 ^cCatchment areas of rivers Mera (127 km²) and Baleo (138 km²).

800 ^dCatchment area at the gauge station for River Mera.

801 ^eRiver discharge normalised to the total catchment area: $R = R_g \cdot C_t / C_g$, where R_g is the river discharge at the gauge
 802 station, C_g is the catchment area at the gauge station and C_t is the total catchment area.

803 ^fAverage for the period 1970–2009 in River Mera (5.9 m³ s⁻¹) and River Baleo (5.9 · 138/127 = 6.4 m³ s⁻¹).

804 ^gAverage for the period 1997–2009.

805 ^hAverage for the period 1975–2009.

806 ⁱAverage for the period 1970–2009.

807 ^jAverage for the period 1941–2009.