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DISTRIBUTION PATTERNS OF THE GOOSENECK BARNACLE (*POLLICIPES POLLICIPES* [GMELIN, 1789]) IN THE CANTABRIA REGION (N SPAIN): EXPLORING DIFFERENT POPULATION ASSESSMENT METHODS

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ABSTRACT The gooseneck barnacle *Pollicipes pollicipes* is a very valuable marine resource on the coasts of Spain and Portugal. To maintain the sustainable exploitation of this species, periodical large-scale population assessments are essential. Because of the heterogeneous distribution of these populations in aggregates, together with the difficulties associated with sampling (i.e., access to rocky reefs, wave exposure, high tides, etc.), there is a lack of studies in this regard. In light of these constraints, the coverage, biomass, and available stock of gooseneck barnacle were first estimated using a novel semiquantitative method along a 215-km long coast at 10 fishing zones and three tidal levels. This study contributed to the first assessment of the distribution variability of gooseneck barnacle in the Cantabria region (N Spain), as the first step toward a long-term monitoring goal. The proposed method is based on a general coverage (GC) estimation, by means of (1) quantitative coverage measurements on quadrats (50 cm × 50 cm) located along vertical transects covering the intertidal bandwidth and corrected by tidal level bandwidths, (2) semiquantitative coverage estimates in larger areas, including 5 m on either side of the quadrats along the transect. Biomass samples were collected at each sampling point by scraping the 50 cm × 50 cm quadrat and fresh weight of the samples was measured. This method arrives at the biomass estimates by means of a power regression model for the coverage–biomass relationship. The population distribution pattern along the coast was also explored separately, by commonly used (1) quantitative coverage estimates in quadrats with no bandwidth correction (sample coverage, SC) and (2) semiquantitative estimates, as in the proposed method (transect coverage, TC), both of which included biomass sampling. Biomass and standing stocks values obtained using GC were lower and consumed less sampling time than those obtained by TC, and particularly SC. The results suggest that the proposed method might be suitable for the assessment of *P. pollicipes* populations in large coastal areas, as it potentially avoids stock overestimation by detecting the spatial distribution heterogeneity and reduces the sampling time.

KEY WORDS: gooseneck barnacle, *Pollicipes pollicipes*, coverage, stock assessment, sampling method, spatial distribution heterogeneity

INTRODUCTION

The gooseneck barnacle *Pollicipes pollicipes* (Gmelin, 1789) is harvested along the East Atlantic coast from Brittany to North Africa (Barnes 1996, Cruz 2000, Molares & Freire 2003, Parada et al. 2012, Jacinto et al. 2010, 2011). In particular, it constitutes a valuable resource in Portugal and Spain (Molares & Freire 2003, Cruz et al. 2015). This species occurs in rocky intertidal and shallow subtidal habitats in highly active shores exposed to dominant swells, often close to high slopes and near caves and crevices (Barnes 1996, Cruz 2000, Pavón 2003, Borja et al. 2006b, Cruz et al 2010). Its populations show an aggregative pattern, typically forming dense aggregates that carpet the substratum in areas of high density, and, to a lesser extent, they form distinct rosette-shaped clusters that are densely packed in some low intertidal areas. In addition to the habitat suitability, some studies have suggested that this heterogeneous distribution of *Pollicipes* sp. is because of their recruitment behavior based on the preferential settlement of cyprids on the peduncles of adults (Barnes & Reese 1960, Hoffman 1988). Living within a cluster of adults might offer juveniles protection from predation, desiccation, and strong wave action (Barnes & Reese 1960), as well as benefits for reproduction; stalked barnacles are simultaneous hermaphrodites and obligate cross-fertilizers that rely on gregariousness to mate with conspecifics (Charnov 1987, Barnes, 1992).

The array of physical factors determining the distribution of the genus *Pollicipes* and their aggregation patterns makes it difficult to sample and estimate the standing stocks (Bernard 1988, Parada et al. 2012) and is probably the main reason behind the lack of large-scale and periodic population assessment studies. Another important factor might be the lack of proper funding for monitoring programs and fisheries-related science associated with this marine resource.

Assessments including coverage estimates, and especially the collection of samples for examining the size structure, length–weight relationships, distribution patterns, and available biomass studies are scarce in the literature and are being carried out mostly at punctual stations or along short stretches of coast in central and SE Portugal (Cruz 2000, Cruz et al. 2010, Sousa et al. 2013) and N Spain (Borja et al. 2006b). To our knowledge, the only extensive studies regarding available biomass along a large stretch of coast in Spain was conducted in the coastal region of Asturias (N Spain) (De la Hoz & García 1993, Pavón 2003). There have been some more studies in the central and southwest coast of Portugal (Cruz et al. 2008, 2015, Jacinto et al. 2010, 2011, Sousa et al. 2013) and in Britanny (France) (Girard 1982). In these studies, the biomass for different fishing zones was estimated using the samples obtained by scraping the rocky surface within quadrats. Parada et al. (2012), among others, describe the application of this technique at exposed rocky shores as very difficult and time consuming. Moreover, the high heterogeneity in the distribution of this species makes it difficult to carry out an estimation of their total coverage and

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standing stocks along extensive stretches of coast using this method. To alleviate the effect of heterogeneity, Borja et al. (2006b) estimated the coverage using a more general semiquantitative visual estimation method. They determined the gooseneck barnacle coverage visually, for an area extending to 5 m on either side of every biomass sampling station, at three tidal levels within the barnacle belt. The visual estimation scale was based on the distribution pattern observed [i.e., without barnacles (0%), solitary individuals (<5%), presence only in cracks (6%–15%), separated aggregations (16%–35%), etc.]. Using these coverage estimates, they calculated the standing stocks for short stretches of coast (100–300 m) by (1) determining the biomass per square meter in a series of samples (i.e., 30 cm × 30 cm quadrats) within the barnacle belt, (2) correcting the biomass by the estimated coverage value, and (3) multiplying the corrected biomass by the study area, which was determined by the coastal line length (m) occupied by the gooseneck barnacle and the intertidal bandwidth (m). This extrapolation of the biomass per area unit to the available biomass in a coastal zone is done deliberately, while ignoring the great heterogeneity of this medium and considering it to be flat. This simplification was assumed together with the fact that the coverage in cracks and cavities was not directly estimated as in Parada et al. (2012).

In the Galicia region (NW Spain), the difficulties in managing large coastal areas for obtaining information on socioeconomic topics, harvesting activities, population dynamics, and stock status, including long-term monitoring of extensive shellfish beds (Parada et al. 2012), forced the regional government to consider small-scale or zone-based management models (Molares & Freire 2003). In this region, area-based programs shared between fishermen associations (“*cofradias*) and the regional government, which assign a specific exploitation area to a person or a group, have been shown to be a suitable approach for the management of *Pollicipes pollicipes* (Molares & Freire 2003). These programs give management responsibilities to fishermen communities, including development of annual management plans and maintaining an appropriate control of the mortality due to fishing (Young 2013). In the coastal areas under wider scale regional management models, new approaches for gooseneck population assessments should be tested, as they face heterogeneous distribution patterns of *P. pollicipes* as well as the difficulties associated with field sampling. This would help achieve a sustainable use of this valuable resource.

In this study, a new procedure for the estimation of coverage, biomass, and standing stocks of gooseneck barnacles was explored with the objective of (1) alleviating the difficulties associated with field surveys and (2) being useful to carry out large-scale characterization of the populations of this species. The estimation procedure is based on a combination of quantitative measurements using quadrats and corrections by tidal-level bandwidths, as well as more general visual coverage estimates, together with a coverage–biomass regression model for biomass estimation. In addition, coverage and biomass estimations were also performed separately by means of general visual estimation incorporated in the proposed procedure and quantitative estimation of quadrats with no tidal-level bandwidth correction. The proposed approach and the other two commonly used methods were explored in terms of the obtained estimates, as well as detection of the heterogeneity associated with the distribution of this species, and the sampling effort. While testing the suitability of this procedure, this study also becomes the first study (1) addressing vertical and horizontal distribution variability of the gooseneck barnacle in the Cantabria region (N Spain) and (2) exploring the effect of protection regimes on coverage and biomass.

MATERIALS AND METHODS

Study Area and Sampling Site Selection

The total study area covered 215 km of coast in the Cantabria region (north Spain) (Fig. 1). First, the suitable habitats of gooseneck barnacle were identified using a compilation of information obtained from cartographic data, professional shellfishers, and technical personnel of the main Directorate of Fisheries of Cantabria (DFC personal communication). Thus, 10 coastal areas, covering a total of 60 km of coastline, were established as potential shellfishing zones. Each of these coastal areas were subjected to different protection levels based on their fishery closure regime: (1) Ubiarco, Liencres, Arnía, Diablo, Llaranza, and Cerdigo (null protection, open all year), (2) Prellezo, Oreña, and Arena (seasonally protected, closed from May 1 to October 1), and (3) Sonabia (permanently protected, closed all year). To carry out the present study, a representative sampling site was established for each of these coastal areas (Fig. 1). The criterion for considering a sampling site (~200–500 m) as a representative of several kilometers long stretch of coast was the importance of the site in terms of the shellfishing (i.e., very important, important, or less important) with respect to the coastal region, for each of the 10 coastal stretches (Stamatopoulos 2002). Using the information compiled from the DFC, the selected sampling sites were deemed “important” in terms of potential fishing with respect to the coastal stretch, to be as geographically representative as possible (i.e., mimic average conditions) for the entire statistical area or the coastal stretch. Accessibility to the sampling sites was similar (Figs. 1 and 2).

Sampling and Laboratory Procedures

Field surveys were carried out during spring low tides in June 2010. At each of the 10 sampling sites, five vertical intertidal transects (i.e., transverse to the intertidal strip) were established along 200–500 m of coastline, except in Cerdigo and Diablo (four transects) and Llaranza (three transects). The transects were located along the entire bandwidth of *Pollicipes pollicipes* occurrence, and according to its vertical distribution, in each transect, three different levels were surveyed [labeled as high (H), medium (M), and low (L)] at regular intervals between the mean lower low water and the upper level of the gooseneck barnacle occurrence bandwidth. This method includes the variability due to the tidal level to analyze the effect of this factor on the variables studied (Parada et al. 2012). The shallow subtidal zone was not sampled, as professional fishing is largely conducted in the intertidal area, which is the main distribution zone for this species (Borja et al. 2006a). Field surveys included visual estimates of coverage and quantitative sample collections for biomass data.

Coverage Sampling

Coverage sampling: A visual estimate was performed within a quadrat of 50 cm × 50 cm with a 5 ×5 grid placed at each of the

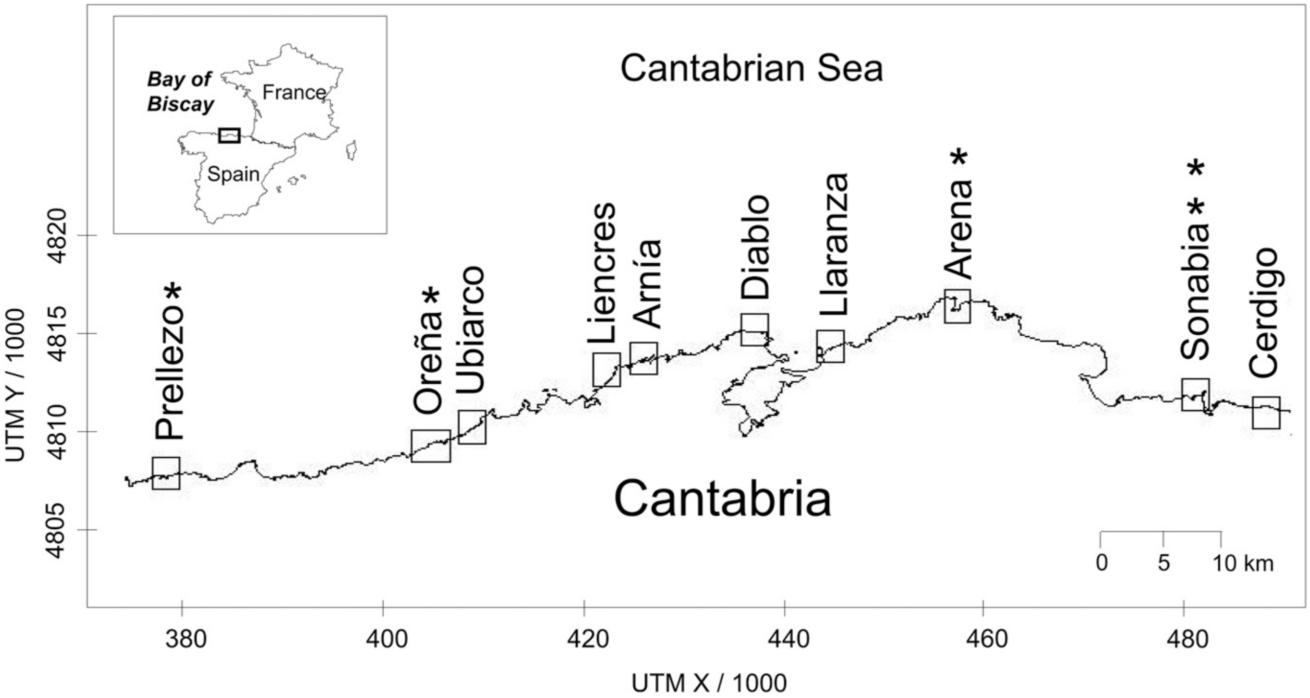

Figure 1. Sampling sites along the coast of Cantabria (Bay of Biscay) located in seasonally protected (*), permanently protected (**), and open-to-fishing (no label) zones.

three sampling levels (H, M, L) along the transect line, following a similar criterion as Parada et al. (2012), but involving the count of number of squares dominated by *Pollicipes pollicipes* instead of using the photo-quadrat method.

Transect sampling: It was estimated visually in the area including 5 m on either side of each transect, following a similar criterion as Borja et al. (2006b) [without gooseneck barnacle, coverage (0%); solitary individuals, coverage <5% (mean 2%); presence only inside cracks, small groups of barnacles, coverage 6%–15% (mean 10%); presence of relatively separated aggregates in rocks and cracks, coverage 16%–35% (mean 25%); presence of close aggregates (<0.5 m) in rocks and cracks, coverage 36%–65% (mean 50%); continuous coverage, very abundant in rocks and cracks, coverage 66%–100% (mean 75%)].

Biomass Sampling

To estimate the biomass, quantitative samples were collected at each sample coverage (SC) sampling point by scraping the 50 cm × 50 cm quadrat. Biomass in each quadrat was calculated by measuring the fresh weight (FW) of the samples within the quadrat. Fresh weight was determined by weighing the samples after removing the attached organisms and draining it to a constant FW. Using these data together with the SC estimates, a regression model for the relationship

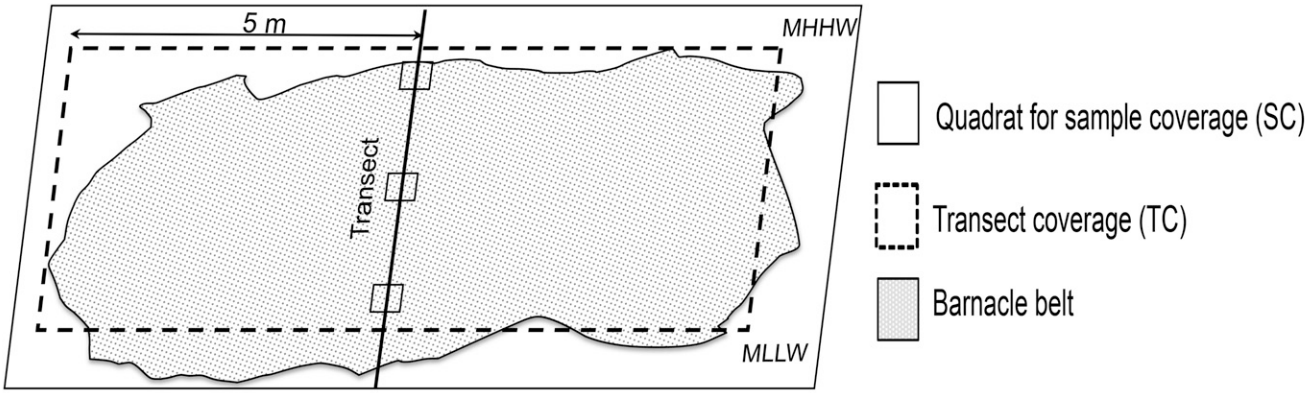

Figure 2. Scheme of coverage estimation in the field (Scale 1:125). In each sampling site, five transects (as the one in this figure) were located 40–100 m apart from one another. SC was determined quantitatively in three 50 × 50 cm quadrats located at three tidal levels (high, mid, low) along a transect covering the barnacle intertidal belt, considering the lowest level at the mean lower low water (MLLW) level and the highest level at the mean higher high water (MHHW) level. TC was estimated by means of visual estimation of the percentage coverage of the area covering 5 m on either side of each transect adapting Borja et al. (2006b).

between coverage (%) and the biomass in FW per surface unit was obtained (Fig. 3). In addition, for each sample, the rostrum–tergum (RT) length (Bidegain et al. 2015) of every individual was measured for size frequency analysis [see the results of this analysis in Bidegain et al. (2015), Fig. 2]. To estimate the proportion of the exploitable biomass and stock, commercial individuals were also weighed separately. For this, individuals >20 mm (RT length) were selected, considering that the minimum catch size in the region of Cantabria is established as 40 mm of total length (peduncle plus capitulum height), which corresponds to an RT length of approximately 20 mm (Bidegain et al. 2015, Fig. 4).

Coverage Estimation

Coverage Estimation Methods

The coverage was estimated by means of commonly used quantitative and semiquantitative approaches and the alternative combined quantitative/semiquantitative procedure proposed in this paper.

The sample coverage (SC) method: The SC method is a commonly used coverage estimation method. Coverage was calculated as an average of the percentage coverage estimated in quadrats [adapted from Parada et al. (2012)] at the two different tidal levels and the whole site.

The transect coverage (TC) method: The coverage of each site was calculated as an average of the coverage estimated in all transects of the site in the area including 5 m on either side of the transects [adapting from Borja et al. (2006b)] (see 2.2.1).

The general coverage (GC) method: To take into account the variability due to the patchiness and heterogeneous distribution of gooseneck barnacle populations, the coverage estimation method proposed in this study involves the estimation of a GC for each site or zone as follows.

The coverage was calculated according to Eqs. 1 and 2. First, a corrected sample coverage (CSC) was calculated for each transect i ($CSCi$) based on the estimated SCs (SC_{ij}) (Guinda et al. 2017) and tidal bandwidths (BW_{ij}) corresponding to each of the three tidal levels (j = high, medium, or low). Next, the GC of the site was obtained according to the CSC_i values, TCs (TC_i) estimated by the TC method described above, and the sum of bandwidths (BW_{ij}). Similarly, the GC at each tidal level "j" was obtained.

$$CSC_i = \frac{\sum\limits_{j=\mathrm{H,M,L}} \left(\mathrm{SC}_{ij} \times \mathrm{BW}_{ij}\right)}{\sum\limits_{j=\mathrm{H,M,L}} \left(\mathrm{BW}_{ij}\right)} \tag{1}$$

$$GC = \frac{\sum\limits_{i=1}^{n} \left(CSC_i \times TC_i \times \sum\limits_{j=H,M,L} \left(BW_{ij}\right)\right)}{\sum\limits_{i=1}^{n} \sum\limits_{j=H,M,L} \left(BW_{ij}\right)} \tag{2}$$

Statistical Analysis

Once all these variables were calculated, a Kruskal–Wallis rank test was performed to explore if there were significant differences in TC, SC, and GC among the sites and the tidal levels (the latter only for SC and GC) at each site. If significant differences were detected among sites ($P < 0.05$), the 95% confidence intervals (CI) were calculated for the differences between sites, following Bidegain et al. (2013), to identify the sites that were significantly different from each other. The test applied considers that when pairing groups, the CI does not contain zero; hence, the null hypothesis that the group means are the same is rejected (du Prel et al. 2009). If significant differences were detected among the tidal levels, Mann–Whitney U tests were performed for each possible pair to identify the levels with significant differences between them. Similarly, differences in the coverage estimates among methods were tested at each site by comparing the coverages obtained by the GC method to those of SC and TC. The variability among samples was also explored using the coefficient of variation (CV), calculated as the SD divided by the mean (means reported in Table 1). In addition, the effect of protection regimes on coverage was explored using the CI test.

Biomass and Stock Estimation

Estimation

First, to convert the coverage (%) data into biomass (kg m^{-2}) data, a nonlinear regression model was constructed using the

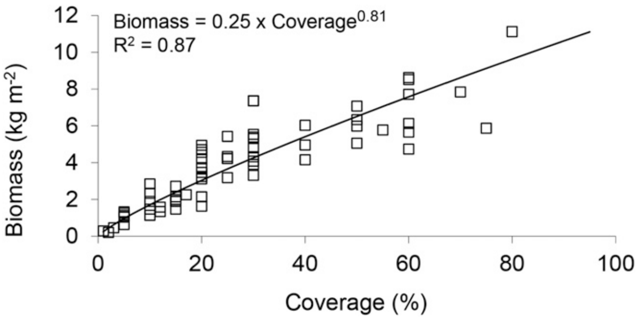

Figure 3. Power regression model of the relationship between coverage (%) and FW biomass (kg m^{-2}) of *Pollicipes pollicipes*.

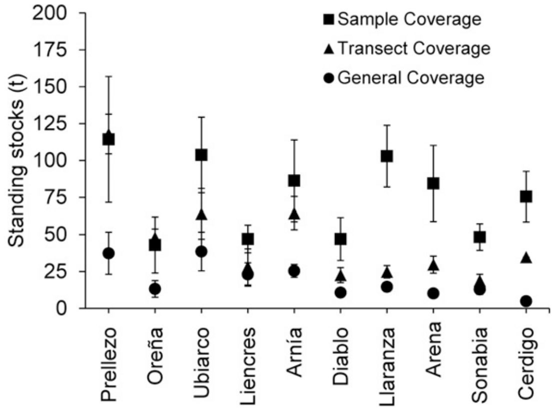

Figure 4. Standing stocks (t) in the 10 coastal stretches along the shore of Cantabria, estimated from coverage values obtained by using (1) 50 × 50 cm quadrats (SC), (2) semiquantitative visual estimations along the transects (TC) and (3) GC estimated through the combination of SC and TC. Error bars represent 95% CI.

TABLE 1.

Coverage estimations of *Pollicipes pollicipes* (%, Mean ± SD) at the 10 studied sites.

Site	SC (%) H	SC (%) M	SC (%) L	SC (%) Total	TC (%)	GC (%) H	GC (%) M	GC (%) L	GC (%) Total
Prellezo	14.6 ± 9.1^{a}	17.0 ± 14^{a}	37.6 ± 18.4^{a}	$23.0 \pm 13.1^{x}_{s}$	$24.0 \pm 5.4^{x}_{s}$	3.6 ± 3.0^{a}	4.1 ± 4.6^{ab}	9.6 ± 6.0^{b}	$5.8 \pm 4.4^{z}_{st}$
Oreña	7.2 ± 8.2^{a}	19.4 ± 14.7^{a}	39.0 ± 18.8^{b}	$21.8 \pm 13.9^{x}_{s}$	$25.0 \pm 6.1^{x}_{s}$	1.5 ± 2.5^{a}	4.4 ± 4.8^{ab}	9.7 ± 6.6^{b}	$5.2 \pm 4.3^{z}_{s}$
Ubiarco	30.0 ± 15.8^{a}	51.0 ± 18.5^{a}	55.0 ± 25.7^{a}	$45.3 \pm 14.8^{x}_{t}$	$25.0 \pm 13.2^{y}_{s}$	8.4 ± 7.5^{a}	14.3 ± 10.7^{a}	15.3 ± 9.1^{a}	$13.4 \pm 9.0^{z}_{ut}$
Liencres	29.0 ± 8.9^{a}	51.0 ± 15.2^{b}	67.0 ± 8.4^{c}	$49.0 \pm 10.8^{x}_{t}$	$26.0 \pm 12.4^{y}_{s}$	11.2 ± 8.6^{a}	22.4 ± 14.8^{a}	23.4 ± 16.0^{a}	$20.4 \pm 13.8^{y}_{u}$
Arnía	15.6 ± 11.8^{a}	28.0 ± 16.9^{a}	38.0 ± 18.7^{a}	$27.2 \pm 15.8^{x}_{s}$	$19.0 \pm 6.5^{x}_{st}$	3.6 ± 2.1^{a}	6.1 ± 2.6^{ab}	7.7 ± 2.5^{b}	$6.1 \pm 2.0^{y}_{s}$
Diablo	11.7 ± 13.8^{a}	26.2 ± 13.5^{b}	52.5 ± 18.6^{c}	$30.1 \pm 15.3^{x}_{s}$	$12.5 \pm 5.5^{y}_{u}$	1.5 ± 0.9^{a}	3.3 ± 1.8^{b}	6.9 ± 3.6^{b}	$5.0 \pm 2.8^{z}_{s}$
Llaranza	30.0 ± 13.2^{a}	43.3 ± 5.8^{a}	70.0 ± 5.0^{b}	$47.8 \pm 8.0^{x}_{t}$	$8.3 \pm 2.8^{y}_{v}$	2.4 ± 1.4^{a}	3.6 ± 1.5^{a}	6.2 ± 2.3^{a}	$4.3 \pm 1.8^{z}_{s}$
Arena	20.0 ± 10.6^{a}	18.0 ± 7.6^{a}	38.0 ± 13.2^{a}	$25.3 \pm 10.5^{x}_{s}$	$7.0 \pm 2.7^{y}_{v}$	2.1 ± 1.3^{ab}	1.2 ± 0.4^{a}	2.7 ± 1.0^{b}	$1.9 \pm 0.8^{z}_{v}$
Sonabia	39.0 ± 12.4^{a}	54.0 ± 17.8^{a}	61.0 ± 21.6^{a}	$51.3 \pm 17.3^{x}_{t}$	$16.0 \pm 7.4^{y}_{t}$	8.2 ± 4.5^{a}	10.3 ± 6.1^{a}	11.4 ± 5.9^{a}	$10.1 \pm 5.3^{y}_{t}$
Cerdigo	5.0 ± 0.0^{a}	12.5 ± 6.5^{b}	13.7 ± 4.8^{b}	$10.4 \pm 3.8^{x}_{u}$	$5.0 \pm 0.0^{y}_{w}$	0.2 ± 0.0^{a}	0.6 ± 0.3^{b}	0.4 ± 0.4^{ab}	$0.4 \pm 0.3^{z}_{w}$
Total	20.3 ± 14.5^{a}	32.1 ± 19.6^{ab}	46.8 ± 21.9^{b}	33.1 ± 18.7^{x}	17.5 ± 8.7^{y}	3.4 ± 3.7^{a}	5.3 ± 6.8^{b}	7.3 ± 4.6^{b}	7.3 ± 5.9^{z}

Sample coverage and GC are presented for high (H), medium (M), and low (L) tidal levels in each site. TC contemplates a unique measure along the intertidal profile. Groups with significant differences (1) between tidal levels (H, M, and L) for SC and GC are represented by *a*, *b*, and *c* letters (superindex) for each site and total (rows), (2) between coverage estimation method (SC total, TC, and GC total) for each site are represented by *x*, *y*, and *z* letters (superindex) (in rows) and (3) between sites for each method are represented by *s*, *t*, *u*, and *w* letters (subindex) in the columns SC total, TC, and GC total.

coverage data of gooseneck barnacles within the samples and their corresponding biomass (FW) (Fig. 3). Introducing the estimated GC in the regression model, the total biomass values of gooseneck barnacles per square meter were obtained for each site and tidal level. To calculate the total standing stocks of gooseneck barnacles in the studied coastal sites, the biomass was multiplied by its corresponding coastal length and intertidal bandwidth. The total stock for the coast of Cantabria was then calculated as the sum of biomasses for the 10 coastal areas established as potential shellfishing zones. The stocks were also calculated separately for each of the three defined tidal levels. Similarly, commercial biomass and stock were estimated per site from individuals >20 mm RT obtained in the laboratory (Table 2). The total standing stocks from SC and TC were estimated incorporating the coverage estimated by each method in the power regression model.

Statistical Analysis

A Kruskal–Wallis rank test was performed to detect the significant differences in biomass among the tidal levels at each site. If significant differences were detected among the tidal levels, Mann–Whitney *U* tests were performed for all possible pairs to identify the levels with significant differences. Moreover, the variability among samples was also explored using the CV. In addition, for exploring the differences among sites in terms of the standing stocks, and the commercial biomass and commercial stocks, the CI test (CI = 95%) was performed (du Prel et al. 2009), which assessed the pairwise differences between sites. The differences were considered significant ($P < 0.05$) when the CI did not contain zero. Following the same CI test, differences in stock estimates among methods (Fig. 3) were also explored at each site by comparing the standing stocks obtained from coverage estimates by GC, SC, and TC methods. In addition, the effect of protection regimes on biomass and commercial biomass was examined using the CI test.

Sampling Duration for Biomass Estimation

Finally, to explore the sampling effort needed to estimate the SC (SC_{st}), TC (TC_{st}), and for the collection of quantitative samples for biomass estimation (B_{st}), the "sampling time" (st) was examined at Ubiarco. This analysis was also used to explore the sampling effort at different tidal levels to evaluate the effect of increasing exposure to wave action at low tidal levels. The total time taken for each biomass estimation method [i.e., "method time" (mt)] (SC_{mt}, TC_{mt}, and GC_{mt}) was calculated as the sum of the time consumed in the sampling procedures that were conducted. Thus, for the SC method, the total time (SC_{mt}) was the sum of the time consumed during the estimation of coverage in quadrats (SC_{st}) and quantitative sampling (B_{st}), whereas for the TC method, the total sampling duration (SC_{mt}) was the sum of the time consumed during the estimation of coverage in transects (TC_{st}) and quantitative sampling (B_{st}). Finally, for the GC method, the total time (GC_{mt}) was calculated as the sum of the time consumed during the estimation of SC (SC_{st}) and TC (TC_{st}). There is no biomass sampling time in this method, as the biomass was calculated using the biomass–coverage regression model (Fig. 3). Only the time spent during the sampling was considered, including the deployment of the quadrat, visual estimation, and collection of individuals. The time spent between transects was not included to avoid site-specific effects.

RESULTS

Coverage Estimation

Sample Coverage

The SC increased while going from higher to lower tidal levels, in all the studied sites (Table 1), ranging from an overall average value of 20.3% in the high intertidal zone to 46.8% in the lower intertidal zone ($H (2, 138) = 32.1$, $P < 0.01$). More specifically, the overall SC at the high tidal level was not significantly different from the medium level, but it was

TABLE 2.

Fresh weight biomass of *Pollicipes pollicipes* (kg m^{-2}) per tidal level (high, medium, low), coastal length (km), intertidal bandwidth (m), standing stock (t), commercial stock (t), and commercial stock density (kg m^{-2}) for each fishing zone.

		Biomass (kg m^{-2})							
Site	**H**	**M**	**L**	**Total**	**Coastal length (km)**	**Bandwidth (m)**	**Stock (t)**	**Stock RT > 20 mm (t)**	**Biomass RT > 20 mm (kg m^{-2})**
Prellezo	0.7 ± 0.6^{a}	0.8 ± 0.9^{a}	1.6 ± 1.0^{b}	$1.1 \pm 0.8_{stu}$	7.4	4.8 ± 0.8	$37.3 \pm 28.2_{s}$	$6.6 \pm 5.0_{s}$	$0.2 \pm 0.1_{s}$
Oreña	0.3 ± 0.6^{a}	0.8 ± 0.9^{a}	1.6 ± 1.1^{b}	$1.0 \pm 0.8_{s}$	5.7	2.4 ± 0.5	$13.2 \pm 11.1_{tu}$	$3.6 \pm 3.0_{st}$	$0.3 \pm 0.2_{s}$
Ubiarco	1.4 ± 1.3^{a}	2.2 ± 1.6^{b}	2.3 ± 1.4^{b}	$2.1 \pm 1.4_{tv}$	5.7	3.3 ± 0.6	$38.6 \pm 25.9_{s}$	$6.2 \pm 4.2_{s}$	$0.3 \pm 0.2_{st}$
Liencres	1.8 ± 1.4^{a}	3.2 ± 2.1^{b}	3.3 ± 2.2^{b}	$2.9 \pm 1.9_{v}$	1.8	4.3 ± 0.7	$23.1 \pm 15.6_{st}$	$4.3 \pm 2.9_{st}$	$0.5 \pm 0.4_{t}$
Arnía	0.7 ± 0.4^{a}	1.1 ± 0.5^{b}	1.3 ± 0.4^{b}	$1.1 \pm 0.4_{su}$	6.7	3.5 ± 0.4	$25.4 \pm 8.5_{s}$	$11.9 \pm 4.0_{u}$	$0.5 \pm 0.2_{t}$
Diablo	0.4 ± 0.2^{a}	0.7 ± 0.4^{ab}	1.2 ± 0.6^{b}	$0.9 \pm 0.5_{s}$	3.5	3.3 ± 0.5	$10.7 \pm 6.1_{u}$	$3.7 \pm 2.1_{st}$	$0.3 \pm 0.2_{st}$
Llaranza	0.5 ± 0.3^{a}	0.7 ± 0.3^{ab}	1.1 ± 0.4^{b}	$0.8 \pm 0.3_{s}$	5.8	3.0 ± 0.4	$14.6 \pm 6.1_{tu}$	3.5 ± 1.5	$0.2 \pm 0.1_{s}$
Arena	0.5 ± 0.3^{a}	0.3 ± 0.1^{a}	0.6 ± 0.2^{b}	$0.4 \pm 0.2_{w}$	8.1	3.0 ± 0.6	$10.2 \pm 4.2_{u}$	$2.1 \pm 0.9_{v}$	$0.1 \pm 0.1_{u}$
Sonabia	1.4 ± 0.8^{a}	1.7 ± 1.0^{a}	1.8 ± 0.9^{a}	$1.7 \pm 0.9_{u}$	3.1	2.5 ± 0.3	$12.9 \pm 6.8_{tu}$	7.6 ± 4.0	$1.0 \pm 0.5_{v}$
Cerdigo	0.1 ± 0.0^{a}	0.2 ± 0.1^{a}	0.1 ± 0.1^{a}	$0.1 \pm 0.1_{w'}$	12.2	3.1 ± 0.6	$4.9 \pm 3.4_{v}$	$1.8 \pm 1.3_{v}$	$0.1 \pm 0.1_{u}$
Total	0.6 ± 0.5^{a}	0.9 ± 0.7^{ab}	1.2 ± 0.7^{b}	1.0 ± 0.6	60.0	3.3 ± 0.5	190.9 ± 116	51.3 ± 28.8	0.3 ± 0.1

Groups with significant differences in biomass between tidal levels (H, M, and L) for each site (row) are represented by different letters (*a*, *b*, and *c*). Groups with significant differences in biomass (Total, kg m^{-2}), in stock (t), commercial stock (t, RT > 20 mm) and commercial biomass (kg m^{-2}, RT > 20 mm) between sites (column) are represented by *s*, *t*, *u*, *v*, *w*, and *w′* letters.

significantly lower than that at the low tidal level. Significant differences between the three tidal levels were detected in Liencres and Diablo. Moreover, in Oreña and Llaranza, significant differences were found between the low tidal level and the other two levels, whereas differences between the high tidal level and the other two levels were observed in Cerdigo. The variability among samples was high ($CV = 0.56$), and a decrease was observed in the CV while going from the high ($CV = 0.71$) to low tidal level ($CV = 0.47$).

Regarding the differences among sites, the SCs obtained for Ubiarco, Llaranza, Liencres, and Sonabia, with mean values ranging from 45.3% to 51.3% (Table 1), were significantly higher than those obtained for Prellezo, Oreña, Arnía, Diablo, and Arena. The lowest, significantly different percentage of coverage was estimated in Cerdigo. The variability in the samples among sites was also important, with very high CV ($CV > 0.50$) observed in Prellezo, Oreña, Arnía, and Diablo. The lowest CV were estimated in Liencres and Llaranza. Significant differences in SC were not detected among the protection regimes.

Transect Coverage

The TC was significantly lower than the SC (Table 1, see Total). In general, the TC was significantly higher in the western sites (Prellezo, Oreña, Ubiarco, Liencres, and Arnía) than in the eastern sites, with the lowest values estimated in Cerdigo. The TC for Sonabia was not significantly different than the estimated value for Arnía. This decreasing TC pattern from east to west was not found for SC. The mean TC for the coast of Cantabria was significantly lower than that obtained for SC. Moreover, TC was also significantly different from SC in all sites, except Prellezo, Oreña, and Arnía. Overall, the variability among samples ($CV = 0.70$) was higher than SC, indicating a lower homogeneity in the data. Significant differences in TC were not detected among the protection regimes.

General Coverage

Overall, the GC was significantly lower than the SC and TC (Table 1) for the total values including all sites, as well as for the individual sites, except Liencres, Arnía, and Sonabia, where the TC and GC did not show significant differences. In addition, the GC was significantly different among the tidal levels ($H(2, 138) = 33.5$, $P < 0.01$). More specifically, the GC at the low tidal level was not significantly higher than that at the medium level, but it was significantly higher than the value at the high tidal level. Besides, no differences among the levels were found in Ubiarco, Liencres, Llaranza, and Sonabia. The detected variance was larger than the other two coverage estimates ($CV = 0.81$), indicating that this approach yielded the lowest homogeneity in data.

The decreasing west–east gradient observed for TC was not seen in the case of GC. The spatial pattern for GC had some similarities with that of SC. For example, the GC in Liencres (13.4%), Ubiarco (20.4%), and Sonabia (10.1%) was significantly higher than the rest of the sites, similar to the SC pattern, with the exception of Prellezo, which was different from Liencres and Ubiarco but not different from Sonabia. Moreover, within this group of sites with high GC, the coverage was not significantly different between Ubiarco and Liencres, or between Ubiarco and Sonabia, whereas it showed a significant difference between Liencres and Sonabia (Table 1). In contrast with the coverage estimated by TC, Llaranza was not one of the sites with the highest coverage in terms of GC. Sonabia, the permanently protected zone, showed a similar coverage to that estimated in Ubiarco but with a considerably lower variance. Similar to the values estimated by SC, the lowest, significantly different GC were found in Arena and Cerdigo. Finally, no significant differences in GC were detected among the protection regimes.

Biomass and Standing Stocks

The relationship between the FW biomass (kg m^{-2}) and SCs (%) estimated over the sampling quadrats followed a power regression model, which explained 87% of the variability (Fig. 3). According to this model, the estimated biomass in a square meter with 100% coverage was 10.67 kg. By applying this regression model to the estimated GC, the gooseneck barnacle biomass (kg m^{-2}) per square meter for each site and tidal level was obtained (Table 2). Overall, the biomass differed among the tidal levels being significantly higher at the low tidal level than at the high tidal level. Cerdigo and Sonabia did not show any significant differences among the tidal levels.

The spatial pattern with respect to the sites was very similar to the pattern for GC. Ubiarco (2.9 kg m^{-2}), Liencres (2.1 kg m^{-2}), and Sonabia (1.7 kg m^{-2}) showed a significantly higher biomass than Diablo, Llaranza, Arena, and Cerdigo. Biomass in Prellezo was not statistically different from the estimated biomass in Ubiarco and Sonabia. Similarly, the biomass in Oreña and Arnía was not different from the value estimated for Sonabia. The lowest values of biomass were estimated in Cerdigo (0.1 kg m^{-2}) and Arena (0.4 kg m^{-2}) (Table 2).

The total standing stock estimated using GC for the 60-km stretch of fishing zone defined in the coast of Cantabria was 191 t (Table 2), which are mainly distributed in the medium (78 t) and low (85 t) tidal levels. Significant differences in standing stock were not found among the western sites Prellezo, Ubiarco, Liencres, and Arnía (20–40 t). These sites had the largest stocks because of a combined effect of elevated biomass and large fishing areas. The decreasing west–east pattern observed for TC and GC was observed for the standing stock as well. The estimated stocks in Oreña, Llaranza, and Sonabia (10–20 t) were not significantly different from the value estimated for Liencres. The permanently protected area of Sonabia did not exhibit a particularly high stock (12.9 t) owing to the fact that it is not a very large area. The stocks in Diablo and Arena were similar to those found in Oreña, Llaranza, and Sonabia but significantly lower than those estimated for Prellezo, Ubiarco, Liencres, and Arnía. The lowest standing stock was observed in Cerdigo (<5 t) even though it is the largest fishing area.

The highest commercial stocks were estimated in Arnía (11.9 t). This was because of the combined effect of a relatively high commercial biomass (0.5 kg m^{-2}) and a large fishing area. Sonabia (7.6 t), with significantly lower biomass than Arnía, also showed a high commercial stock, explained mainly by the fact that the highest commercial biomass was also observed in this permanently protected site (1.0 kg m^{-2}) (Table 2). This protected site did not show significant differences in commercial biomass in comparison with Prellezo, Ubiarco, and Liencres. Similarly, the biomass in Oreña, Diablo, and Llaranza was not significantly different from the estimated biomass in Prellezo, Ubiarco, and Liencres. The commercial stocks were significantly lower in Arena and Cerdigo than the rest of the sites because of the low values of commercial biomass in these sites.

Comparing the stocks estimated by the three methods (SC, TC, and GC), the total estimated standing stock [mean (lower 95% CI, upper 95% CI)] using GC [191 t (132,250)] was significantly lower than that using SC [753 t (544,962)] and TC [453 t (362,533)] (Fig. 4), with the TC estimate being significantly lower than the SC estimate as well. As for the variance of these estimates, the average CV was higher for GC (71%) in comparison with SC (62%) and TC (44%).

In this sense, the standing stocks, as estimated using SC, were significantly lower in Liencres and Sonabia than in the rest of the sites, except Oreña and Diablo. These two latter sites were not significantly different from Arnía, Arena, and Cerdigo. For TC, in addition to Liencres and Sonabia, Diablo, Llaranza, Arena, and Cerdigo also showed lower standing stocks than the rest of the sites. In the case of GC, the estimated coverage in Oreña, Diablo, Llaranza, Arena, Sonabia, and Cerdigo was significantly lower than the estimates for Prellezo, Ubiarco, and Liencres, with the exception that Liencres was not significantly different from Oreña.

As for the effect of protection regime on biomass, significant differences were found only for commercial biomass. The estimated commercial biomass in the permanently protected site (Sonabia) was significantly higher than the estimates for seasonally protected and nonprotected sites. No differences were found between seasonally protected and nonprotected sites.

Sampling Duration

As shown in Table 3, whereas the SC and TC coverage sampling took 9.2 (SC_{st}) and 11.8 (TC_{st}) min, respectively, to cover the five transects, the quantitative sampling for biomass required 54.2 min (B_{st}). As for the tidal levels, the low tidal level required the highest sampling time (almost double the time required for the high tidal level). Thus, the overall biomass estimation for the site took 63.4 and 66 min, respectively. The time needed for GC estimation was 21 min. This time is obtained by adding the time needed to estimate the SC and TC coverage, that is, the sum of SC_{st} and TC_{st}.

DISCUSSION

This study was the first to address the distribution variability of gooseneck barnacles in the Cantabria region (N Spain). The methodology proposed in this work has been demonstrated to be a suitable approach for large-scale stock assessment of gooseneck barnacle populations. The results provide consistent support for the conclusion that the proposed approach of the

TABLE 3.

Sampling duration at Ubiarco. Above, time (min) needed for estimating the SC in quadrats (SC_{st}) and in transect coverage (TC_{st}), and for the collection of individuals for biomass estimations (B_{st}).

	Sampling duration (min)			
Measurement	**H**	**M**	**L**	**Total**
SC_{st}	1.7	2.5	5.0	9.2
TC_{st}	2.5	3.5	5.8	11.8
B_{st}	12.5	16.7	25.0	54.2
Biomass estimation method	**Sampling duration (min)**			
	H	**M**	**L**	**Total**
$SC_{mt} = (SC_{st} + B_{st})$	14.2	19.2	30	63.4
$TC_{mt} = (TC_{st} + B_{st})$	15.0	20.2	30.8	66.0
$GC_{mt} = (SC_{st} + TC_{st})$	4.2	6.0	10.8	21.0

Below, sampling time needed to obtain data for biomass estimations with different methods (SC_{mt}, TC_{mt}, and GC_{mt}) resulted by the sum of the coverage estimates and individual's collection times needed to estimate the biomass (below). The subindex 'st' and 'mt' represent the sampling time and the method time (sum of sampling times), respectively. The duration at each tidal level (H, high; M, medium; and L, low) is the sum of times of five transects recorded at that level, considering only deployment of the quadrat, visual estimation, and collection of individuals. Time consumed between transects is not included.

GC method is potentially better at detecting the heterogeneity associated with the distribution of this species, resulting in more conservative estimates than those obtained with the SC method and the TC method. These estimates seem to be more consistent with the capture data obtained from the DFC than the SC and TC estimates. The estimates of annual harvest are around 15% of the commercial stock (DFC personal communication). The method proposed here estimated the total stock at 190 t including 51 t of commercial stock. Considering the annual declared capture (6 t; DFC personal communication), this estimate yields an annual harvest at 12% of the commercial stock. The TC and SC methods resulted in stock estimates of 453 t (122 t of commercial stock) and 753 t (203 t of commercial stock), respectively, resulting in significantly lower stock estimates than GC and yielding likely unrealistic annual harvesting/commercial stock ratios around 5%. The fact that a high percentage of the stock is not harvestable may not only be due to the legal size of the individuals but also because most of the gooseneck barnacle stock is in areas with low density and coverage, which potentially result in low capturability fishing areas (i.e., captures/effort), unsuitable for an intensive commercial harvesting.

In addition, the GC procedure consumes lesser time than the other methods, which require a quantitative sampling of the quadrats. To systematically compare these methods and provide a better test of their accuracy, the next step would be to compare the estimates of these three methods with a new quantitative and more accurate coverage estimate. This coverage would be estimated for a site by means of multiple photoquadrats of size 50 cm × 50 cm, covering the whole area from mean higher high water to mean lower low water and 5 m to either side of each transect.

Considering the sampling site (~200–500 m) as a representative of several kilometers long stretch of coast in terms of the site importance with respect to the shellfishery potential (i.e., very important, important, and less important) might have limitations. The problem is that preselection of sampling sites runs the risk of biased samples if the sites are not a representative of the entire statistical area (Stamatopoulos 2002). The entire statistical area or coastal stretch would be better represented by including more replicates in each coastal stretch and applying a more statistically representative sampling method, such as planned rotational approach. Given the various operational constraints (i.e., accessibility, availability of data collectors, limited mobility, etc.), the application of such "more representative" sampling methods might not be too feasible. Thus, data collection from sampling sites at the studied fixed locations might be tolerable for the purpose of long-term monitoring and assessment (Stamatopoulos 2002), in light of the operational constraints.

The obtained coverage and stock estimates for GC were significantly lower than those obtained using the other two tested methods; at the same time, the variance was higher, indicating a lower homogeneity of the data (Tables 1–2, Fig. 4). Second, the sampling time was significantly shorter, as this method saves time by estimating biomass from a previously obtained biomass–coverage regression model, rather than collecting samples in the field (Table 3). The results of this study are discussed in the context of (1) differences in coverage, biomass, standing stocks, and sampling time between the approach tested in this study (GC) and the classic quadrat-based (SC) and transect-based (TC) assessment methods, and (2) detection of the spatial variability in the distribution of this species and the effects of fishery closure.

The quantitative estimates (SC) using quadrats showed similar mean values, with considerably higher variability (CV = 0.56), in comparison with the data for the neighboring coast of Asturias (CV < 0.25), as estimated by Pavón (2003) using similar methods. A less random sampling method, together with a larger number of samples, used in this study (10 per tidal level) could be the reason for the observed difference in variability between the two studies. Moreover, the semiquantitative coverage estimates (i.e., TC) were considerably lower than that obtained by Borja et al. (2006b) (34.6%) using a similar method in the neighboring zone of Gaztelugatxe Marine Reserve. Taking into account that the permanently protected zone of Sonabia also showed a lower coverage value (16.0%) than Gaztelugatxe, factors other than the reservation might explain these differences (e.g., environmental conditions and subjectivity associated with this sampling method). The variance associated with their estimates in the reserve (CV = 0.40) was similar to that found in Sonabia (CV = 0.46), with both being smaller than the variance of seasonally protected and nonprotected sites. The approach to estimate the GC by a combination of these two sampling methods (i.e., GC) showed considerably lower values and higher variance than those found by each of these methods, in both this study and previous studies mentioned above, thus, suggesting that the GC approach, despite being more conservative, seems to be more suitable to detect heterogeneous distributions of this species.

The power regression model used to estimate the biomass and consequently, the standing stocks from the coverage data, explained 87% of the variability. The regression model was developed with coverage data (%) and biomass data (kg m^{-2}) from quantitative estimation in 50 cm × 50 cm quadrats, and then applied for the coverage data obtained by the SC (quantitative estimates), TC (semiquantitative estimates), and GC (combination of both) methods. Because the regression model was developed using the data obtained from quantitative samples, the use of the model for the coverage data estimated using less quantitative methods, such as TC and GC, might result in an *a priori* inaccuracy in the estimates that may require further analysis. At least for GC, the biomass estimates might be suitable for detecting the heterogeneous distribution of this species, as seen for the coverage estimates. Borja et al. (2006b) reported the successful application of a similar logarithmic regression model, which explained 61% of the observed variability. Discrepancies with this study might be explained mainly by the larger dataset available in the present study together with differences in wave exposure due to the differential shadow effect caused by Bay of Biscay along the north coast of Spain (Bento et al. 2012) and other environmental conditions such as nutrient availability (García-Soto et al. 2002).

The obtained relationship between coverage and biomass might support the gooseneck barnacle biomass and standing stock estimates obtained from the coverage data. The use of this correlation constitutes a less time-consuming alternative to the quantitative sampling process of scraping a defined surface. Yet, management strategies for this resource also need to be supported by the population structure data to determine, for example, the proportion of commercial-sized barnacles in the population biomass. This issue should be addressed by a combination of a more frequent coverage monitoring with a less frequent biomass-based monitoring. Another possibility is photo-based sampling, followed by photo analysis for not only coverage estimation purposes (Parada et al. 2012) but also for size frequency analysis by digitally estimating the RT or RC length.

In this study, the sampling time associated with the collection of individuals in a site with five transects and three tidal levels was estimated (Table 3). The GC stock assessment method was the least time-consuming method. This is because this approach does not require quantitative sampling, in contrast with the SC and TC methods. The biomass estimates for the SC and TC methods needed similar sampling times, as both procedures involve quantitative sampling. The fact that time spent in TC was slightly higher than SC was because of the relatively larger estimation area in TC. As expected, both coverage estimation and sample collection showed increased sampling times at lower tidal levels. This result is explained by the higher number of interruptions suffered at lower tidal levels due to the exposure to wave action and the consequent rise in sea level. Thus, the difficulties in carrying out the stock assessment, as mentioned by Bernard (1988), are clearly minimized using this method of biomass estimation. As shown by recent studies, the sampling time could be significantly reduced using photo-quadrats for coverage estimation.

In addition to significantly higher stock estimates for GC than those obtained for SC and TC, the variance of these estimates was also 20%–30% higher for GC (CV = 65%) than SC (CV = 55%) or TC (CV = 35%). It should be noted that the SC estimation is based on quadrats established in the zones where the gooseneck barnacles are present, which explains the potential overestimation of the biomass values obtained using this procedure. The TC estimation is based on the coverage percentage of the sampling site area with a noticeable presence of gooseneck barnacles (Borja et al. 2006b). This gives an idea about the heterogeneity of their distribution, but potentially overestimates the real coverage because in a visual estimate of a large area (5 m toward either side of the sampling site) categorizing ranges of cover into discrete bins (Borja et al. 2006b), surveyors might tend to overestimate gooseneck barnacle coverage particularly for low coverage (Boudouresque 1971, Edwards & Tinker 2009). This result suggests that overall, the methodology proposed here may correct the effect of the heterogeneity in gooseneck population distribution and their patchiness when compared with the other methods. As the obtained results are lower than those obtained by the other methods, it can be said that these results lay on the side of caution, resulting in more conservative biomass estimates and may lead to more strict management measures.

Despite the high variance of the data, the method was able to detect the spatial variability in terms of tidal level and sites, yielding higher biomass and coverage at the lower tidal levels, together with a higher commercial-sized individual density in the permanently protected area of Sonabia (Table 2). The effect of seasonal protection of the zones was not detected. These results are consistent with the previous spatial distribution data for this species in N Spain (Pavón 2003) and recent studies conducted in this coast to test the suitability of management measures (Bidegain et al. 2015). The higher growth rate of individuals at the low tidal level (Cruz 2000), associated with the longer feeding time (Barnes 1996, Barnes & Reese 1960) and the higher settlement rate (Cruz et al. 2010), appears to be the main reason for the differences observed among tidal levels.

Similar to this study, Borja et al. (2006b) observed a substantial positive effect with respect to the density and abundance of large-sized individuals in permanently protected zones of the neighboring coast of Basque Country. In fact, Bald et al. (2006) suggested establishing permanently closed fishing areas and/or alternate exploitation of different coastal areas, allowing the recovery of the resource after the capture season as the best management action. Bidegain et al. (2015) also suggest that the seasonal protection regime might not be adequate for highly overexploited populations. They recommended a longer fishery closure of at least 2.5 y in the situations requiring a total recovery.

On the contrary, Cruz (2000) and recently, Sousa et al. (2013), using a similar analysis to that conducted by Bidegain et al. (2015), did not find any significantly positive effect in terms of the percentage of cover and the density of large individuals in the no-capture areas of central and SW Portugal. Similarly, the hypothesis of a high percentage cover, density, and biomass in the low shore compared with the mid shore was not supported by these studies. Regarding the effect of the protection regime, Sousa et al. (2013) suggested that the absence of the protection effect could be because most of the restrictions on exploitation are recent, with frequent changes, and are not well respected. Regarding the coverage and biomass, they found that higher densities, percentage cover, and biomass are observed at the midshore than at the low shore, yet the low shore barnacles have a higher proportion of adults with moderate and high commercial value, whereas juveniles are relatively more abundant at the midshore (Sousa et al. 2013). This observation could be explained by the combined effect of a much faster growth (Cruz et al. 2000) and a much higher fishing effort at low shore compared with the mid and upper shore levels. As suggested by Parada et al. (2012), although the lack of association of the coverage and biomass with the tidal level in the studies in Galicia and Portugal (Parada et al. 2012, Sousa et al. 2013) might appear to contradict the results reported here and in Pavón et al. (2003), this is expected, considering that the fishing zones studied here are subject to much less intense exploitation than those in Galicia or SW Portugal. That is, in general terms, the exploitation intensity is higher at the low shore because of the *a priori* presence of larger individuals and the best quality in terms of the market value of gooseneck barnacles in this tidal fringe (Pavón 2003). This fact could limit the tidal level effect on the coverage and biomass of gooseneck barnacles in intensely and professionally fished areas. The difficulties associated to fishing at lower tidal levels (Molares & Freire 2003), together with less professional and intense fishing compared with Cantabria, could result in the coverage and abundances to remain higher at the low tidal level.

Sonabia presents the highest biomass density (kg m^{-2}) of commercial-sized individuals, demonstrating the efficient performance of the permanent fishery closure established in this coastal area. In this site, however, because of the small size of this fishing area, the standing stock is lower than that found in other sites with relatively lower densities of large individuals (Table 2). Apart from the protected area of Sonabia, Liencres and Arnía seem to be the least exploited zones and constitute the best fishing zones, as they present relatively elevated gooseneck barnacle coverages and a high proportion of commercial-sized individuals. On the contrary, even though Prellezo and Ubiarco showed higher standing stocks, they cannot be considered as good fishing zones because of the low proportion of commercial-sized individuals therein.

CONCLUSIONS

In conclusion, it can be said that the tested method (GC) is suitable for extensive assessment of *Pollicipes pollicipes* populations in large coastal areas. Using a combination of SC quantitative coverage estimates, corrected using bandwidth and semiquantitative TC estimates, this method avoids potential stock overestimation by the spatial distribution heterogeneity at the microscale and mesoscale levels. In addition, it is less time consuming than the other methods, which require a quantitative sampling of multiple quadrats. This approach successfully circumvented two important constraints faced by large-scale periodic population assessment studies: the highly heterogeneous distribution of the gooseneck barnacle populations and the limited availability of time for carrying out the surveys. Yet, this approach could be potentially improved in terms of reducing the sampling time, by the use of photo-quadrats (Parada et al. 2012, Sousa et al. 2013). The saved sampling time could then be used for obtaining the biomass and population structure data from the samples, by scraping the surface of small quadrats (e.g., 25 cm × 25 cm). Furthermore, in this study, only one sampling site per fishing zone was considered, and although each site was selected on the basis of being a representative of its fishing zone (see section Study Area and Sampling Site Selection for the selection criteria), this limits the comparisons within and among different fishing areas, as no proper replication was performed. This limitation could also be addressed, without taking much extra time, by photo-quadrat-based replication in addition to a quantitative sampling.

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