Measuring the abundance and diversity of a waterbird community: numbers or biomass?

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Research on the use of foraging space by bird guilds in the Comacchio Lagoon (Northern Italy), has shown that measures of abundance (number of individuals, overall biomass and consuming biomass) can affect the figure of the spatial distribution of the foraging guilds and of some parameters of the entire community. The spatial distributions of each guild were highly correlated any way they were measured. At the community level, the spatial distributions of abundance, density and diversity (both of guilds and of species) yielded by the three measure methods were highly correlated at the scale of the overall lagoon, whereas some difference emerged between number-based and biomass-based measures at a more detailed scale.

Key words: abundance, overall biomass, consuming biomass, density, diversity, guilds, Italy, spatial distribution, waterbird community, Comacchio Lagoon.

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During research on the use of foraging space by bird guilds, depending on the availability of food resources, and the composition and structure of the waterbird community, we faced the problem of finding the most effective measure of bird abundance.

The 69 waterbird species that have been recorded at Comacchio Lagoon vary greatly in weight: the heaviest species (*Cygnus olor*) is 350 times heavier than the lightest (*Calidris minuta*). When taking into account only the regularly occurring species, the ratio between the heaviest (*Anser anser*) and the lightest (again *Calidris minuta*) is 123. Although undoubtedly lower, there is a difference (up to 10 times) among the weights of the species within each guild. This suggested to us that we could measure bird abundance as overall biomass and consuming biomass, as well as number of individuals.

This work follows on from an analysis of the spatial variation of the composition and structure of the waterbird community foraging in the Comacchio Lagoon, based upon consuming biomass measures (Boldreghini & Dall'Alpi 2003). Here we examine the effect of the different methods of measuring abundance against the spatial distribution of each guild and of the abundance, density and diversity of the entire foraging waterbird assemblage.

Material and methods

Study area

The Comacchio Lagoon (locally named "Valli di Comacchio") is a coastal wetland complex that was formed by the subsidence caused by the shift northwards of the main branches of the Po River delta in the 12th century. It is located (44°36'N, 12°10'E) in the southern part of the delta of the River Po, facing the northern Adriatic Sea. It has been managed over past centuries for extensive rearing of euryhaline fish (mainly Eel *Anguilla anguilla*, but also Boyer's Sand Smelt *Atherina boyeri*, mullets *Mugilidae*, Sea Bream *Sparus aurata*, Sea Bass *Dicenthrarchus labrax*, and Flounder *Platichthys flesus*) and,

Figure 1. The study area and its sectors.
Àrea d'estudi i els seus sectors.

to a least extent, for salt extraction. The lagoon's connection with the sea has been under human control as a result of the fishery (or salt extraction) annual cycle. Presently the system, which is the last remnant of a huge brackish-water wetland system that was reclaimed mainly for agriculture during the first half of the 20th century, covers some 120 km^2 and is almost completely embanked. The average water depth is 60 cm, with a maximum depth of 2 m. The Lagoon is polihaline, usually supplied with saltwater from the sea between autumn and early spring and with freshwater from the River Reno and drainage canals during late spring. The salinity changes seasonally and is higher (up to some 50‰ in certain zones) in late summer, due to evaporation. Water level decreases from spring to autumn. An ecological account of the area is given by Corbetta (1990) and more concisely by Grimmet & Jones (1989). Ardizzone *et al*. (1988) described how typical Italian fishing "valli" work.

The study area covers 54.2 km^2, just under half the total surface of the Lagoon, and includes all types of habitat and human management. It has been divided into 33 sectors, depending on their main ecological features and human use (Figure 1): A – K - belonging to two wide water bodies which take salt- and freshwater under human control, used for extensive fish-culture; L – U - a set of smaller basins used for semi-extensive fish-culture under a more strict control; V – X - belonging to a lagoon openly connected to the Adriatic Sea; UW, UE, MN, LM, EP, ES, SF, BS, LA - a set of abandoned saltwater basins and salt-pans.

Methods

Censuses were carried out between two and four times every month, from December 1996 to November 1999, except for the sectors belonging to the abandoned salina, which were censused from September 1999 to August 2000.; Hunting days and unfavourable weather conditions (fog, strong wind, heavy rain etc.) were avoided, and 10x binoculars and 20-60x telescopes were used. Each survey started early in the morning and was usually completed early in the afternoon, by two observers who covered standard routes by driving or walking. Only counts of individuals observed feeding in each definite sector (i. e. actually exploiting the trophic resources of that ecosystem) were taken into account; average numbers over the entire sampling period were used in the analysis.

The species were arranged into guilds (or trophic categories) according to general knowledge on the main food in similar areas and seasons (Cramp & Simmons 1977, 1980, 1983 and Cramp 1985) and, where available, to research carried out in the area (Boldreghini *et al*. 1988, Fasola *et al*. 1989, Bogliani *et al.* 1990, Fasola & Bogliani 1990 and P. Boldreghini unpubl. data). The following 15 guilds were defined:

Swimming ichthyophagous: *Podiceps cristatus, Phalacrocorax carbo, Mergus serrator*

Wading ichthyophagous: *Nycticorax nycticorax, Egretta garzetta, Casmerodius albus, Ardea cinerea, A. purpurea*

Flying ichthyophagous: *Larus genei, Sterna caspia, S. bengalensis, S. sandvicensis, S. hirundo, S. albifrons, Pandion haliaetus*

Omnivores: *Larus ridibundus, L. cachinnans*

Swimming invertebratophagous: *Tachybaptus ruficollis, Podiceps nigricollis*

Flying invertebratophagous: *Chlidonias hybridus, C. niger*

Probers: *Philomachus pugnax, Gallinago gallinago, Limosa limosa, Numenius phaeopus, N. arquata, Tringa erythropus*

Peckers: *Himantopus himantopus, Charadrius dubius, C. hiaticula, C. alexandrinus, Pluvialis apricaria, P. squatarola, Calidris alba, C. minuta, C. ferruginea, C. alpina, Tringa totanus, T. stagnatilis, T. nebularia, T. ochropus, T. glareola, Actitis hypoleucos, Arenaria interpres*

Scythers: *Platalea leucorodia, Phoenicopterus roseus, Tadorna tadorna, Recurvirostra avosetta*

Malacophagous: *Aythya fuligula, A. marila, Bucephala clangula*

Predators of ground animals: *Larus melanocephalus, Gelochelidon nilotica*

Raptors: *Circus aeruginosus, C. cyaneus, C. pygargus*

Dabbling phytophagous: *Cygnus olor, Anser fabalis, A. albifrons, A. anser, Anas penelope, A. strepera, A. clypeata*

Diving poliphagous: *Aythya ferina, Fulica atra*

Dabbling poliphagous: *Anas crecca, A. platyrhynchos, A. acuta, A. querquedula.*

The abundance of each guild can been measured as the number of individuals, as overall biomass and as consuming biomass. The assessed overall biomass (i.e. the weight according to Cramp & Simmons 1977, 1980, 1983 and Cramp 1985, but taking into account the season and the geographical area where the species' weights had been recorded) and the consuming biomass (i.e. the weight raised to the 0.7th power according to Salt 1957) of each recorded species are exposed in Table 1. The assessment of the consuming biomass should allow a more effective comparison among birds of different size, because the low metabolic activity per weight unit of the big species is adjusted to that of the smaller species (Salt 1957).

Table 1. Overall biomass (assessed from literature) and consuming biomass (calculated) of the recorded species.
Biomassa bruta (a partir de la literatura) i biomassa consumida (calculada) de les espècies estudiades.

Species	Overall biomass (g)	Consuming biomass (g)
Tachybaptus ruficollis	190	39
Podiceps cristatus	936	120
Podiceps nigricollis	387	65
Phalacrocorax carbo	2200	219
Nycticorax nycticorax	636	92
Egretta garzetta	405	67
Casmerodius albus	1223	145
Ardea cinerea	1430	162
Ardea purpurea	994	125
Platalea leucorodia	1545	171
Phoenicopterus roseus	3052	275
Cygnus olor	9500	609
Anser fabalis	2771	257
Anser albifrons	2081	210
Anser anser	3309	291
Tadorna tadorna	1069	132
Anas penelope	639	92
Anas strepera	793	107
Anas crecca	301	54
Anas platyrhynchos	1042	130
Anas acuta	722	100
Anas querquedula	321	57
Anas clypeata	584	86
Aythya ferina	843	112
Aythya fuligula	766	104
Aythya marila	1049	130
Bucephala clangula	853	113
Mergus serrator	1090	134
Circus aeruginosus	629	91
Circus cyaneus	402	67
Circus pygargus	322	57
Pandion haliaetus	1571	173
Fulica atra	820	110
Himantopus himantopus	176	37
Recurvirostra avosetta	328	58
Charadrius dubius	38	13
Charadrius hiaticula	58	17
Charadrius alexandrinus	46	15
Pluvialis apricaria	199	41
Pluvialis squatarola	208	42
Calidris alba	56	17
Calidris minuta	27	10
Calidris ferruginea	68	19
Calidris alpina	53	16
Philomachus pugnax	143	32
Gallinago gallinago	104	26
Limosa limosa	271	50
Numenius phaeopus	351	60
Numenius arquata	752	103
Tringa erythropus	145	33
Tringa totanus	119	28
Tringa stagnatilis	66	19
Tringa nebularia	174	37
Tringa ochropus	80	21
Tringa glareola	62	18
Actitis hypoleucos	53	16
Arenaria interpres	111	27
Larus melanocephalus	286	52
Larus ridibundus	270	50
Larus genei	286	52
Larus cachinnans	924	119
Gelochelidon nilotica	233	45
Sterna caspia	630	91
Sterna bengalensis	204	41
Sterna sandvicensis	252	48
Sterna hirundo	122	29
Sterna albifrons	51	16
Chlidonias hybridus	88	23
Chlidonias niger	63	18

The Shannon index H' (Odum 1971) has been used to estimate the diversity of the entire waterbird assemblage foraging in each sector. Spearman's rank correlation coefficient has been used to compare the spatial distributions of the guilds and of the parameters of the community obtained, using the three different measures of abundance.

Results

The distribution of the abundance (measured as number of individuals, as overall biomass and as consuming biomass) of each guild in the 33 sectors is shown in Figure 2. The comparison of the distributions of each guild obtained using the three measures of abundance has shown a very high correlation in every case ($0.934 \leq r_S \leq 1.000$, $p < 0.0001$).

The spatial distribution of the abundance of the entire waterbird assemblage is shown in Figure 3. A very high correlation has been found among the three measures of abundance: number *vs* overall biomass: $r_S = 0.866$, number *vs* consuming biomass: $r_S = 0.923$, overall biomass *vs* consuming biomass: $r_S = 0.983$, all $p < 0.0001$.

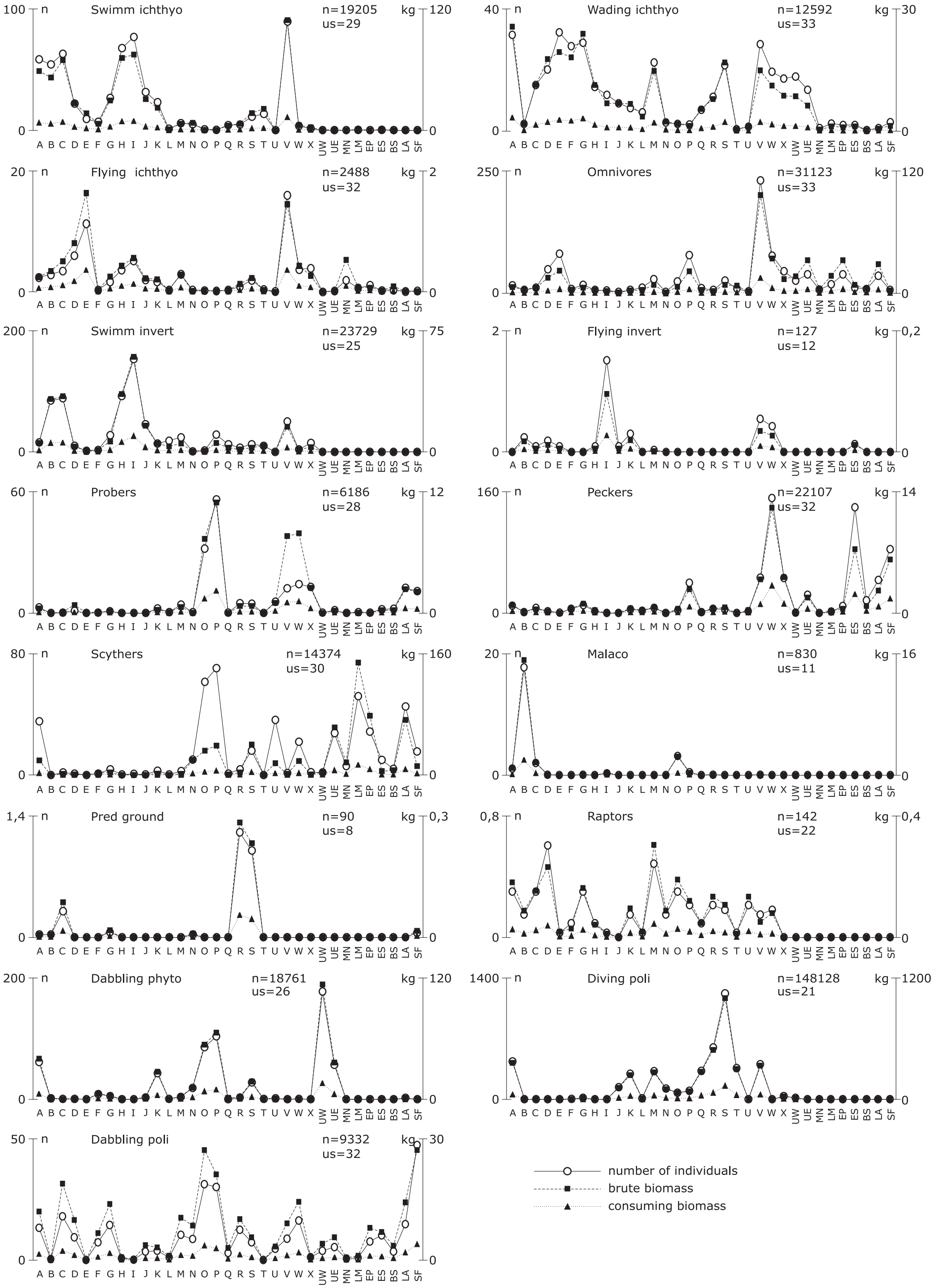

Figure 2. Spatial distribution of the abundance of each guild obtained employing the three measures (n = total amount of sighted birds; u.s. = number of used sectors).
Distribució espacial de l'abundància de cada comunitat obtinguda utilitzant les tres mesures (n = nombre total d'aus comptades; u.s. = nombre de sectors utilitzats).

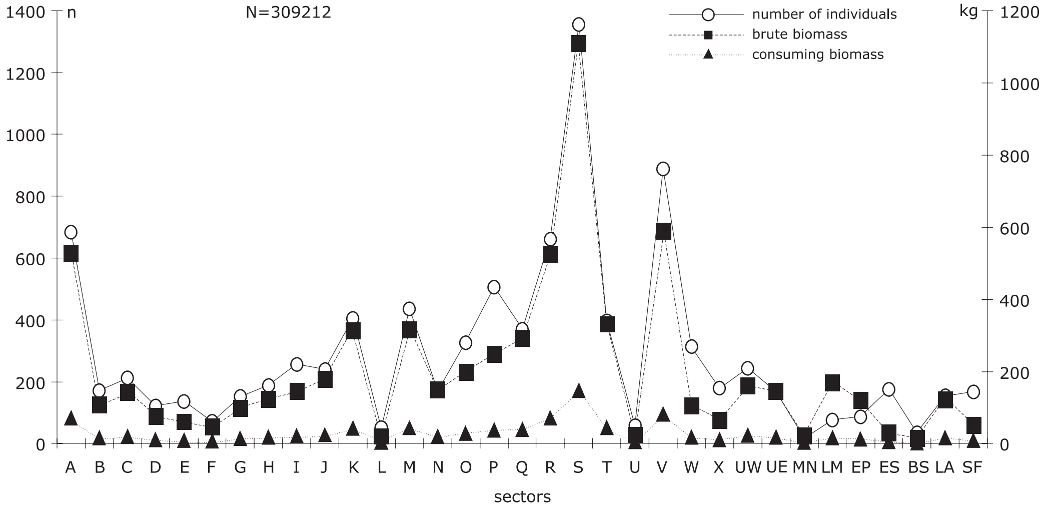

Figure 3. Spatial distribution of the abundance of the entire waterbird assemblage obtained employing the three measures (brute= overall biomass; n = total amount of sighted birds).
Distribució espacial de l'abundància de les aus aquàtiques estudiades utilitzant les tres mesures (brute= biomassa total; n = nombre total d'aus comptades).

There was a lower degree of overlap of the three values in the subset of small sectors belonging to the salina (from UW to SF): effectively, in this case, no correlation was found between number-based values and each of the biomass-based values (*vs* overall: r_S =0.417, *vs* consuming: r_S = 0.583, both n.s.), whereas there was a high correlation between the overall and consuming biomass values (r_S = 0.95, p = 0.0001). Testing other subsets of sectors of similar amplitude, very high correlation levels have been found when comparing all the

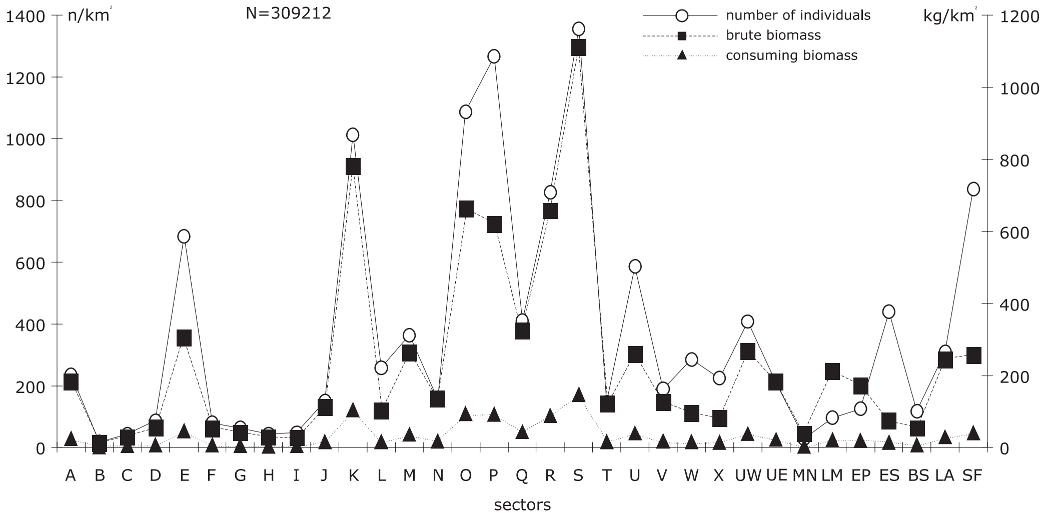

Figure 4. Spatial distribution of the density of the entire waterbird assemblage obtained employing the three measures. (brute= overall biomass; n = total amount of sighted birds).
Distribució espacial de la densitat de les aus aquàtiques estudiades utilitzant les tres mesures (brute= biomassa total; n = nombre total d'aus comptades).

pairs of measures, as well as testing the overall set of sectors.

The spatial distribution of the density of the entire waterbird assemblage is shown in Figure 4. A high correlation has been found between number-based and both biomass-based values (*vs* overall: $r_S = 0.882$, *vs* consuming: $r_S = 0.904$, both $p < 0.0001$) and an even higher correlation between the two biomass-based measures ($r_S = 0.993$, $p < 0.0001$). Also, with regard to the density, in the subset of small sectors belonging to the salina no correlation has been found between number-based and overall biomass-based measures ($r_S = 0.60$, n.s.), whereas a low significance level has been found between number-based and consuming biomass-based measures ($r_S = 0.683$, $p = 0.042$); a high correlaton has been found between the two biomass-based measures ($r_S = 0.967$; $p < 0.0001$).

The spatial distribution of the diversity values obtained from the three measures of the importance of guilds or of species is shown in Figure 5. With regard to guild diversity, a high correlation has been found between number-based values and both biomass-based values (*vs* overall: $r_S = 0.843$, *vs* consuming: $r_S = 0.874$, both $p < 0.0001$); a higher correlation has been found between the two biomass-based values

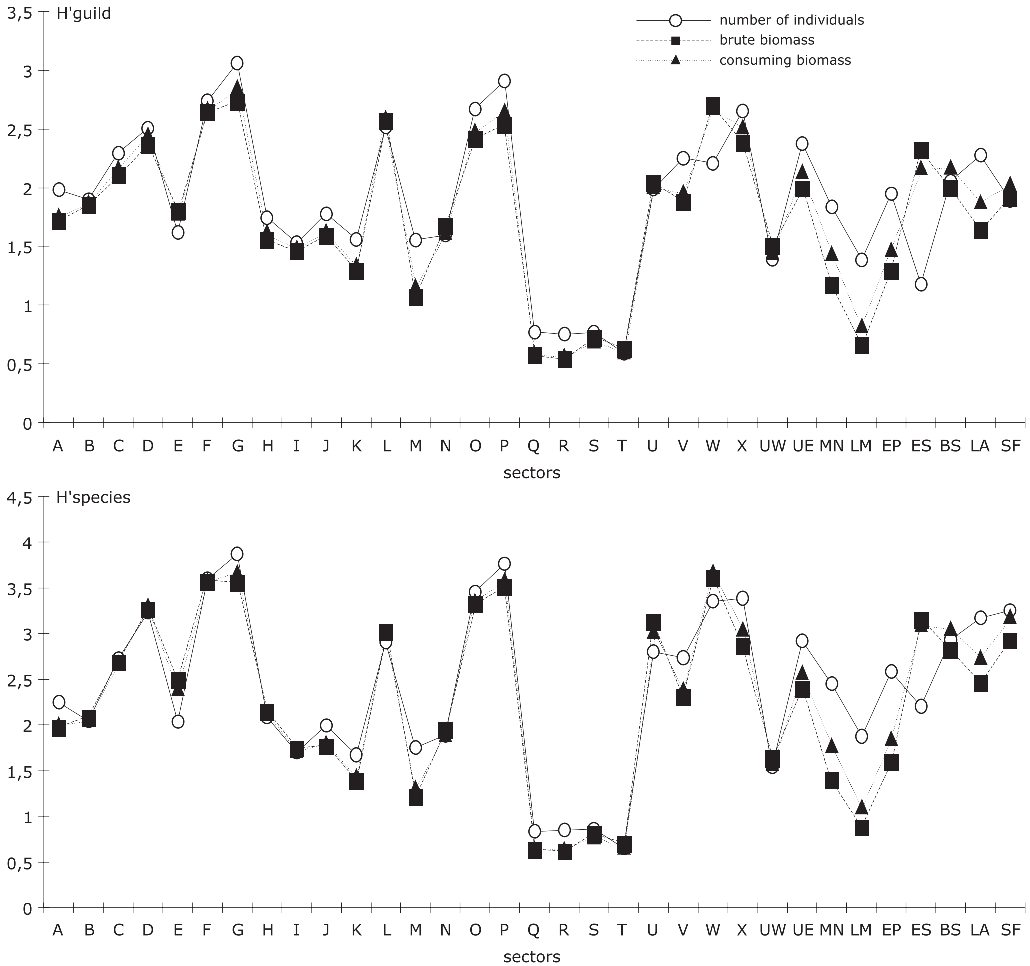

Figure 5. Spatial distribution of the diversity of the entire waterbird assemblage obtained employing the three measures of the importance of guilds or of species (brute= overall biomass).
Distribució espacial de la diversitat de les aus aquàtiques estudiades utilitzant les tres mesures de la importància de les comunitats o de les espècies (brute= biomassa total).

Table 2. Correlation coefficients ($p < 0.0001$) between guild diversity values and species diversity values obtained employing the importance values yielded by the three measures of the abundance.
Coeficients de correlació (p < 0.0001) entre la diversitat de les comunitats i la de les espècies obtingudes utilitzant els valors d'importància produïts per les tres mesures d'abundància.

		H' guild		
		Number	Overall biomass	Consuming biomass
	Number	0.93	0.87	0.91
H' species	Overall biomass	0.80	0.97	0.97
	Consuming biomass	0.82	0.98	0.96

($r_S = 0.99$, $p < 0.0001$). A similar result has been obtained with regard to species diversity: number *vs* overall biomass: $r_S = 0.89$, number *vs* consuming biomass: $r_S = 0.931$, overall biomass *vs* consuming biomass: $r_S = 0.987$, all $p < 0.0001$. Again the subset of small sectors belonging to the salina has been tested separately; with regard to guild diversity no correlation has been found between number-based and biomass-based values (*vs* overall: $r_S = 0.217$, *vs* consuming: $r_S = 0.367$, both n. s.), whereas a high correlation has been found between the two biomass-based values ($r_S = 0.967$, $p < 0.0001$); with regard to species diversity no correlation has been found between number-based and overall biomass-based values ($r_S = 0.50$, n. s.) and a low significance level has been found between number-based and consuming biomass-based values ($r_S = 0.717$, $p = 0.03$), whereas a high correlation has been found between the two biomass-based values ($r_S = 0.933$; $p = 0.0002$).

When comparing all the guild and species diversity values, highly significant correlations have been found in all cases; the coefficients are reported in Table 2. Comparisons between the number-based diversity values and between both biomass-based values have produced very high correlation coefficients, but comparisons between the number-based and biomass-based diversity values produced lower correlation coefficients. A very high correlation has been yielded by the comparison of H' guild to H' species values when computed by the same abundance measure.

Discussion and Conclusion

The three methods used to measure the abundance of waterbirds have not produced any differences to the spatial distribution of each guild, nor to the community parameters, at the scale of the overall study area. Also, to a lesser extent, no difference was found if the sectors were medium or large in size. On the contrary, there was a difference between number-based and biomass-based community parameters in a minor area which is divided into small sectors; it is the small size of the sectors that can be influenced by a strong dominance of one or few species and the size of these can affect the value of the biomass-based parameters.

We can conclude that there is no difference between overall and consuming biomass measures and the choice between number-based and biomass-based measures may depend on further research. It is likely that counts of numbers are sufficient when dealing with populations, whereas biomasses are more effective when dealing with ecological factors, such as carrying capacity, trophic webs, energy flow and interactions between bird and human exploitation of the trophic resources of the wetlands.

Furthermore the spatial distribution of the waterbird diversity does not appear different when computed by guild or species abundance, as has been found when looking at the temporal variation (P. Boldreghini unpubl. data).

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Resum

Mesurant l'abundància i diversitat d'una comunitat d'aus aquàtiques: nombre o biomassa?

En el marc d'un estudi sobre l'ús de l'espai d'alimentació per part de les comunitats d'ocells en la llacuna Comacchio (Nord d'Itàlia), s'ha verificat si el mètode de mesurar les abundàncies (nombre d'individus, biomassa bruta i biomassa consumida) pot afectar els patrons de distribució espacial de les comunitats i d'alguns paràmetres del conjunt de la comunitat. La distribució espacial de cada comunitat va estar molt correlacionada independentment de com es mesurés l'abundància. A escala de comunitat, la distribució espacial de l'abundància, així com la densitat i la diversitat (tant de comunitats com d'espècies) calculades a partir de les diferents mesures van estar altament correlacionades a escala de llacuna, però hi va haver alguna diferència entre les mesures basades en nombre i biomassa a una escala més detallada.

Resumen

Midiendo la abundancia y diversidad de una comunidad de aves acuáticas: ¿número o biomasa?

En el marco de un estudio sobre el uso del espacio de alimentación por parte de las comunidades de aves en la laguna de Comacchio (norte de Italia), se verificó si el método de medir la abundancia (número de individuos, biomasa bruta y biomasa consumida) puede afectar a los patrones de distribución espacial de las comunidades y de algunos parámetros del conjunto de la comunidad. La distribución espacial de cada comunidad estuvo muy correlacionada independientemente de cómo se midió la abundancia. A escala de comunidad, la distribución espacial de la abundancia, así como la densidad y la diversidad (tanto de comunidades como de especies) calculadas a partir de las diferentes medidas estuvieron altamente correlacionadas a escala de la laguna, pero hubo alguna diferencia entre las medidas basadas en número y biomasa a una escala más detallada.

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