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ORIGINAL PAPER

The diet of Atlantic Yellow-legged Gulls (*Larus michahellis atlantis*) at an oceanic seabird colony: estimating predatory impact upon breeding petrels

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Abstract The diet and breeding ecology of Yellow-legged Gulls (*Larus michahellis atlantis*) were studied on Selvagem Grande, North Atlantic in the nesting season of 2007. We collected and analyzed 715 pellets from adults. The most frequent prey were White-faced Storm-petrels (*Pelagodroma marina*; present on 40.8% of all pellets) and the endemic land snails (*Theba macandrewiana*; present on 36.5% of all pellets). Other birds, namely Cory's Shearwaters (*Calonectris diomedea*), Macaronesian Shearwaters (*Puffinus assimilis*), Bulwer's Petrels (*Bulweria bulwerii*), and Band-rumped Storm-petrels (*Oceanodroma castro*) were relatively less frequent, but overall, seabirds were present in ca. 50% of all pellets, representing an estimated 60.4% of all mass consumed by gulls. We estimate that the contribution of seabirds to the overall caloric balance accounted for 82.5% of all energy consumed. The number of gull pairs breeding on Selvagem Grande was 12 on 2005 and 2007. Breeding success was low (0.92 and 0.25 juveniles per breeding pair, respectively). Using a simple bioenergetics model, we estimate the breeding gull population to have the potential to consume approximately 4,847 adult/sub-adult seabirds in 3.5 months in order to meet its energetic requirements. The importance of the estimated predation levels is discussed and some management actions are suggested.

Keywords Predation · Selvagens · Pelagodroma · Calonectris · Bioenergetics

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Introduction

Large gulls (*Larus* spp.) are widespread seabird predators. They may play an important role in the population regulation of several prey species, namely auks (Alcidae) and petrels (Procelariiformes). Typically, on islands, the seabird prey includes species of small body size, particularly storm-petrels (Hydrobatidae; e.g., Vidal et al. 1998; Stenhouse and Montevecchi 1999; Oro et al. 2005).

During the last century, there were marked population increases of several large gull species throughout the world; among other factors, the organic waste available at refuse tips and landfills and, especially, fish offal and discards originating on an ever-growing fishing industry have been implicated as important causes for rapid population increase in large gulls (e.g., Spaans 1971; Furness et al. 1992; Oro et al. 1995; Duhem et al. 2008; but see Harris 1970 and Belant et al. 1993). Such changes led to overpopulation in many areas, which in turn resulted in disproportionate predation rates where gulls coexisted with small petrels and other seabird prey (e.g., Stenhouse and Montevecchi 1999; Oro et al. 2005 and references therein). The impact of predation levels on prey populations can be very severe, particularly when anthropogenic or alternative natural prey resources become scarce; and in some cases, management measures have been applied, albeit with variable success (Oro et al. 2005 and references therein; Oro and Martínez-Abraín 2007).

The Selvagens archipelago (consisting of the islands Selvagem Grande, Selvagem Pequena and Ilhéu de Fora) is classified as an important bird area (Costa et al. 2003) and holds internationally important populations of several seabirds: Cory's Shearwaters (*Calonectris diomedea*), Macaronesian Shearwaters (*Puffinus assimilis*), Bulwer's Petrels (*Bulweria bulwerii*), White-faced Storm-petrels

(*Pelagodroma marina*), and Band-rumped Storm-petrels (*Oceanodroma castro*). A small population of Atlantic Yellow-legged Gulls (*Larus michahellis atlantis*) also nests in the archipelago (Equipa Atlas 2008).

Seabirds, particularly White-faced Storm-petrel and Bulwer's Petrel, are known to represent important items in the diet of Yellow-legged Gulls at Selvagem Grande (Mougin and Stahl 1981; Jouanin and Roux 1965; Jouanin 1974; Den Hartog et al. 1984). However, these early studies were based on small samples collected over small periods, usually a few weeks.

In this paper, we examine Yellow-legged Gull diet and nesting population and estimate the impact of gull predation during the breeding season on seabirds in the Selvagens Islands with an emphasis on the important White-faced Storm-petrel population. In order to estimate the number of seabirds consumed by the breeding gulls, we make use of a simple bioenergetics model (e.g., Phillips et al. 1999; Votier et al. 2004; Matias and Catry 2008), utilizing information on the diet, energetics of adult and chicks, and breeding parameters of Yellow-legged Gulls.

Materials and methods

Study area

This study was carried out at Selvagem Grande (30º 08′N, 15º 52′W), Selvagens Islands, North Atlantic, from May to September 2007 (with preliminary observations in 2005), during the breeding season of most seabirds nesting on that island. Selvagem Grande is the largest island of this group with an approximate area of 267.5 ha (Granadeiro et al. 2006); high cliffs surround the central plateau of this dry volcanic island (maximum altitude of 154 m).

The Selvagens archipelago also include Selvagem Pequena ca. 14 km to the southwest of Selvagem Grande and Ilhéu de Fora about 1 km away from Selvagem Pequena; and additional data were gathered on both.

Population sizes and phenology

An estimated 36,000 pairs of White-faced Storm-petrels nest on Selvagem Grande (Campos and Granadeiro 1999), 25,000 breed on the nearby Selvagem Pequena and at least a few thousands on Ilhéu de Fora (Equipa Atlas 2008), the three sites representing by far the most important nesting area in the North Atlantic. The Selvagens hold almost all of the breeding population of the subspecies *Pelagodroma marina hypoleuca* (with few pairs in the Canary Islands: Rodríguez et al. 2003), a concentration that renders this population somewhat vulnerable. These petrels arrive at their nesting grounds by the end of December, lay their eggs from mid March, and the young fledge until the beginning of August (Campos and Granadeiro 1999). Bulwer's Petrels are abundant breeders on Selvagem Grande but their numbers are unknown (probably in the order of a few thousands). They nest among boulders, in rock cavities and crevices, and in man-made stone walls; they arrive in May, lay from early June, and the latest chicks fledge by early October. Band-rumped Petrels nest in the same habitat as Bulwer's Petrels from late March to October and again from August to March in two separate (but overlapping) episodes and are very common; again, there are no population estimates, but a few thousand individuals should nest during each breeding episode. Cory's Shearwaters are numerous (ca. 30,000 breeding pairs; Granadeiro et al. 2006), and start laying in late May; hatching takes place around mid-July. Macaronesian Shearwaters nest before most petrels in Selvagem Grande, with the latest chicks fledging by late May; a minimum of ca. 2,000 pairs nest on the island (Moniz et al. 1997). The Yellow-legged Gull breeding season starts around mid-March and complete clutches can be found around mid-April. Hatching takes place from mid-May onwards and the chicks fledge 35-40 days later being fed by the parents for some more weeks (Cramp and Simmons 1983; Matias and Catry personal observation).

Gull population

A complete census of the breeding Yellow-legged Gull population was carried out on Selvagem Grande from May to July, and both the plateau and the cliffs were systematically searched. The accessible occupied territories were visited regularly to determine breeding success. Also, regular (usually weekly) counts of non-breeding birds were made on the island during the study period. Population data from Selvagem Pequena and Ilhéu de Fora were obtained by Nature Reserve wardens. Additionally, a bibliographic review was made in order to collect previous population estimates.

Diet sampling

In 2007, pellets and prey remains were collected systematically in most known breeding territories of Selvagem Grande, every 2 days during May and every 2 weeks in July, August, and September. On four territories, pellets were collected on only one occasion in July due to the difficulty of access. To avoid double counting of dietary items, all pellets and prey remains were removed in each visit. The contents of each pellet were analyzed (by disaggregating them carefully) and prey items were identified to the species level whenever possible using a reference collection made for this purpose in the beginning of the study. Pellets were also searched outside the breeding territories on the plateau, with special attention paid to non-breeder roosting areas (clubs).

Bioenergetics model

We developed a simple bioenergetics model (for the breeding season only) making use of several breeding parameters published for other populations of Yellow-legged Gull or for similar species. These parameters show little variation throughout the species range, even between closely related taxa. Thus, we considered an average incubation period of 29 days (Cramp and Simmons 1983), a chick-rearing period of 37.5 days (Cramp and Simmons 1983) and an average clutch size of two eggs. Other parameters incorporated into the model, such as breeding success and number of breeding pairs, resulted from the present study.

The assimilation efficiency of Yellow-legged Gulls has not been measured; however, being a generalist species, it is likely similar to that of the Great Skua (*Stercorarius skua*; see Hilton et al. 2000) and so it was set at 0.76 for all kinds of food (Phillips et al. 1999).

Determination of the energy requirements of gulls

In order to determine the daily energy required by one average adult gull, we used a specific allometric formula for estimating the field metabolic rate (FMR) of warm water seabirds: kJ/day=9.16 (gbodymass)$^{0.646}$ (Birt-Friesen et al. 1989). There are no published data on body masses of the breeding gulls of the Selvagens or Madeira and so we used values obtained at Essaouira on the Atlantic coast of Morocco (Beaubrun and Pons, unpublished data) where adult birds averaged 980 g (SD=75.9, n=17, both sexes combined). We took into account the energy needed for egg formation, which was calculated by multiplying the mean clutch size by the mean fresh egg mass, and then by the average caloric density of larid eggs (6.45 kJg^{-1}), and by the inverse of the egg tissue synthesis efficiency (0.75), following Phillips et al. (1999). Egg mass (85 g) was obtained from Van Klinken (1992) for the Herring Gull (Larus argentatus).

The total amount of energy needed for one gull chick from hatching to fledging (about 6 weeks of age) was calculated using the formula: metabolizable energy (kilojoules needed to fledge)=35.15×M$^{1.015}$, where M is mass in grams (Drent et al. 1992). As we could not distinguish between the food ingested by adults and brought to chicks in the collected pellets, we had to assume that the diet of chicks did not differ significantly from that of adults (we acknowledge that this is often not the case; Spaans 1971). We estimated the amount of energy consumed by all chicks (fledged) multiplying the above value by the number of breeding pairs and then by the breeding success.

Energetic content of prey and their relative importance

The relative energetic importance of each diet component on gull diet was estimated using the energetic value of each prey item, the average mass of a meal of each prey type; and their relative importance in Yellow-legged Gull diet, estimated from the analyzed pellets. Knowing the absolute energetic needs of one gull (FMR, see above), the percentage of that required energy coming from each prey type was estimated and afterwards reverted into absolute number of individual prey items ingested by one gull.

The caloric equivalents used (fresh mass) were 10.9 kJg^{-1} for all birds (Phillips et al. 1999), 8.0 kJg^{-1} for eggs (Carey et al. 1980), 7.0 kJg^{-1} for lizards (approximate value adapted from Konecny (1987), considering 75% of water content), 5.2 kJg^{-1} for fish (Phillips et al. 1999), 6.7 kJg^{-1} for insects (Coleoptera; Stiven 1961; Robel et al. 1995), 4.0 kJg^{-1} for crab (Lindsay and Meathrel 2008), 1.9 kJg^{-1} for goose barnacles (Phillips et al. 1999), and 3.0 kJg^{-1} for snails (Lindsay and Meathrel 2008).

Each pellet containing Bulwer's petrel, White-faced, or Band-rumped storm-petrels was considered to be equivalent to a meal of one individual as each contained typically only one pair of legs.

In order to estimate the average original mass of land snails included on each pellet, we weighed a random sample of pellets containing broken snail shells (N=18, average mass=7.06 g). Then, we estimated the number of snails originally eaten, by dividing the weight of each snail pellet by the average mass of one empty shell of the same snail species (N=11, average mass=0.26 g). A sample of live snails (N=14, average mass=1.26 g) allowed us to determine the mass of digestible matter contained in one live snail (≈0.99 g). Finally, we multiplied this value by the number of snails contained in each pellet and estimated the original digestible fresh mass of ingested snails (average mass of ingested snails per pellet=26.6 g).

The average masses for other prey were taken from various references (see Table 2). For birds, we considered that only 65% of the reference value was in fact digestible and of high energetic value (see Phillips et al. 1999; Votier et al. 2004). For eggs, we considered the shell as weighing 6% of the fresh mass. For the various crab species, we arbitrarily assumed that only 50% of the digestible mass was in fact ingested; the digestible mass equals 42% of the total fresh mass (R. Matias, unpublished data). For unidentified crab, we used the average between the values obtained for the two most frequent species. Prey considered to be very rare or accidental were not considered in the model.

Results

Population numbers

There were 12 breeding pairs of Yellow-legged Gulls nesting on Selvagem Grande both in 2005 and 2007 (Table 1). In 2007, the number of non-breeders on Selvagem Grande was highly variable, ranging from 1 to 25 (average=5.8, SD=7.2, n=11). In 2007, Selvagem Pequena and Ilhéu de Fora had two pairs each.

There are references to Yellow-legged Gulls nesting on the Selvagens since at least the nineteenth century (Schmitz 1893). Available population estimates are scarce and fragmentary but indicate that a low number of (resident) breeding birds have been present through the years usually ranging from 10 to 25 breeding pairs with no clear population trend (Table 1).

Breeding success

On Selvagem Grande, the overall breeding success (number of juveniles fledged per pair) was 0.92 (SD=1.00, N=12) in 2005 and 0.25 (SD=0.62, N=12) in 2007. On Selvagem Pequena and Ilhéu de Fora, the breeding success was unknown but apparently low.

Diet

We collected and analyzed 715 pellets on Selvagem Grande, of which only 14 were found outside breeding territories. Most pellets (96.4%) contained a single-prey item. The White-faced Storm-petrel was by far the seabird most frequently eaten with adults and fledged juveniles present in 40.8% of all pellets; we were not able to distinguish with certainty between those two age classes (when primaries were fully grown) and therefore we included all under one single category called “adults”. Other seabirds were taken in much lower numbers, with Band-rumped Storm-petrels and Bulwer’s Petrels present in 4.8% and 2.9% of the pellets, respectively. Seabirds altogether were found in ca. 50% of all pellets (Table 2). Selvagens endemic land snails (*Theba macandrewiana*) were frequently eaten (found in 35.0% of the pellets), and apparently in large numbers. Crabs (two species) and insects (mainly tenebrionid beetles) were also frequent in the gull diet (Table 2). The Yellow Shore-crab (*Eriphia verrucosa*) and one large octopus beak were recovered from one pellet each and were considered to be accidental items.

Fish was found in only 0.3% of all pellets. Whole dry fish (two Parrotfish *Sparisoma cretense* and one Ornate

Table 1 Numbers of Yellow-legged Gulls on Selvagem Grande

Date	Breeding pairs	Non-breeders	Notes	Source
Sep 1892	-	-	No estimates, breeding confirmed	Schmitz 1893
Late Apr 1895	About 12	-	“Nests” (1 with eggs); downy young	Ogilvie Grant 1896
Jun 1945	?	Not mentioned	11 adults, 1 juvenile Possibly included an undetermined number of non-breeders	Lockley 1952
July 1963	10	-		Jouanin and Roux 1964
May-Jul 1969	?	-	100 adults	Zino 1971
Apr 1973	10++	Ca.15	60++ adults and sub-adults, marked increase noted since 1963	Jouanin 1974
May-Jun 1980	?	2 (2nd years)	50-60 individuals	Den Hartog et al., 1984
Jul 1980		-	16 individuals in 3 weeks	Mougin and Stahl 1981
Dec 1980	Ca. 25	8 juveniles	Around 30 following ship; the estimate of breeding pairs has limited value as it was made in December	Jensen 1981
18.08.1987		-	4 ads, 2 juveniles	Moore 1988
Jun 2005	12	5-10		This study
May-Sep 2007	12	1-25		This study

Table 2 Adult breeding Yellow-legged Gull diet on Selvagem Grande in 2007, estimated mass and energy content of different prey types and meals and energetic contribution of each prey type to overall energetic balance

	Item fresh mass (g)	Meal fresh mass (g)	Meal energy content (kJ)	Frequency of occurrence (%, *N*=715 pellets)	Percentage of energy provided by each prey type
Bulwer's Petrel (*Bulweria bulwerii*)					
Adult	103.5 (1)	67.3	733.3	2.9	8.1
Fledgling	120 (2)	78.0	850.2	0.3	0.9
Egg	21.7 (1)	20.4	163.2	0.1	0.1
Cory's Shearwater (*Calonectris diomedea*)					
Egg	101.7 (1)	95.6	764.8	0.6	9.0
Macaronesian Shearwater (*Puffinus assimilis*)					
Chick	170 (3)	110.5	1204.5	0.1	0.6
White-faced Storm-petrel (*Pelagodroma marina*)					
Adult	50.3 (4)	32.7	356.4	40.8	55.3
Chick	60 (5)	39.0	425.1	0.7	1.1
Egg	13.8 (6)	12.9	103.8	0.3	0.1
Band-rumped Storm-petrel (*Oceanodroma castro*)					
Adult	45.2 (1)	29.4	320.2	4.8	5.8
Berthelot's Pipit (*Anthus berthelotii*)	16.5 (7)	10.7	116.9	0.1	0.1
House Martin (*Delichon urbicum*)	15 (7)	9.8	106.3	0.1	0.1
Unidentified seabirds					
Birds	74.4 (8)	48.4	527.1	0.4	0.8
Chick	40.0 (9)	26.0	283.4	0.3	0.3
Egg	17.6 (8)	16.5	132.4	0.4	0.2
Madeiran Wall-lizard (*Teira dugesii*)	6.5 (10)	4.2	29.6	0.8	0.1
Unidentified fish	-	100.0 (11)	520.0	0.3	0.6
Insects (Tenebrionidae)	-	15.0 (12)	100.5	4.3	1.7
Sally lightfoot crab (*Grapsus webbi*)	168.4 (13)	35.4 (13)	141.5	3.1	1.7
Tidal Spray Crab (*Plagusia depressa*)	86.3 (14)	18.1 (14)	72.5	2.0	0.5
Unidentified crab	127.3 (15)	26.7 (15)	106.9	4.5	1.8
Goose Barnacles *Lepas* sp.	-	40.0 (11)	76.0	1.7	0.5
Land Snails (*Theba macandrewiana*)	1.26 (16)	26.6 (16)	79.8	35.0	10.6

Mass values were taken from the following sources: (1) Robertson and James (1988); (2) approximate mass extrapolated from Nunes and Vicente (1998); (3) an arbitrary mass of 170 g was considered based on an average adult mass of 156.5 g (Robertson and James 1988); (4) Campos and Granadeiro (1999); (5) arbitrary value extrapolated from Campos and Granadeiro (1999); (6) calculated from the formula weight=0.548×length×breadth^2 (Hoyt 1979) using values from Campos and Granadeiro (1999); (7) Cramp (1988); (8) average mass of eggs/adult Bulwer's Petrels and Madeiran Storm-petrels combined (from Robertson and James 1988); (9) arbitrary value for small unidentified petrels, based on our own experience and the apparent size of the bones; (10) R. Matias personal data; (11) from Phillips et al. (1999) for Great Skuas, probably an overestimation; (12) arbitrary value for a large meal of insects; (13): average value of a random sample from Selvagem Grande (*N*=8, SD=±52.1), of which 42% is digestible matter, R. Matias unpublished data; (14) average value of a random sample from Selvagem Grande (*N*=8, SD=±17.4), of which 42% is digestible matter, R. Matias unpublished data; (15) average value of 12 and 13 combined; (16) this study, see "Materials and methods" section

Wrasse *Thalassoma pavo*) were found on two territories apparently indicating scavenging. Vertebrate bones (Sheep *Ovis aries*) found on one occasion indicate that a small percentage of the diet can have an anthropogenic origin, probably collected near the nature reserve station. This item and other non-identified items were not included in the energetic model.

On Selvagem Pequena, a small sample of pellets (*N*=24) from adults contained mostly White-faced Storm-petrels (present in 83.3% of the samples, one individual per pellet), Goose Barnacles (*Lepas* sp., in 12.5% of the pellets), and unidentified crab (in 4.2% of the pellets). These results indicate an even higher reliance of Yellow-legged Gull diet on White-faced Storm-petrels on this island when compared to Selvagem Grande.

Prey consumption model

Energetic requirements of Yellow-legged Gulls

Adult Yellow-legged Gulls were estimated to ingest 784 kJday^{-1} to meet their energy requirements during the breeding season. The energy required to produce an average clutch of two eggs was estimated to be 1,462 kJ per female; we further assumed (from personal observations) that some pairs would produce a second (replacement) clutch; thus, we multiplied the previous value by an arbitrary (but plausible) value of 1.2 which yields 1,754.4 kJ per female per breeding season. One chick would need a total of ca. 38,200 kJ to reach the fledging age. We did not take into account the population of non-breeders present on the island as the number of pellets we collected was too small.

Importance of seabirds on gull diet

The White-faced Storm-petrel was the most important prey in terms of total mass and of energy contribution as well (Tables 2 and 3). Overall, we estimate that seabirds represented 60.4% of all mass consumed by gulls in Selvagem Grande. This is equivalent to 82.5% of all energy consumed.

According to our model, a breeding population of 12 gull pairs (Selvagem Grande only) would consume approximately 4,847 adult seabirds during 3.5 months (Table 3). Assuming that chicks had a similar diet to that of adults, the additional energy necessary for 0.25 chicks pair^{-1} (2007) to fledge would result in the consumption of 211 adult seabirds, and for 0.92 chicks pair^{-1} (2005) would result in 778 additional adult seabirds predated (assuming diet proportions were similar to those of 2007). The consumption by chicks that died before fledging was not considered (the age at death was usually unknown) and these results are not included in the totals presented in Table 3.

Discussion

The results from our study confirm that burrowing petrels, in particular the White-faced Storm-petrel, form a large percentage of the Yellow-legged Gull diet at Selvagem Grande. Land snails, a food item that is poor in energy content, are also taken in large quantities, which may suggest that food resources other than seabirds are relatively scarce or difficult to obtain in the Selvagens.

Previous studies focusing on the diet of gulls in Selvagem Grande relied on very small samples, although they broadly coincide with our results. Jouanin and Roux (1965) and Jouanin (1974) studied 17 pellets and found the White-faced Storm-petrel to be the most frequent prey (76.5% of all pellets). On the other hand, Mougin and Stahl (1981) studied 117 prey remains and pellets (pooled) and found the Bulwer's Petrel to be the most frequent prey, being present in 35.9% of that sample. In these studies, fish were invariably nearly absent from samples.

Prey consumption model: possible sources of error and inaccuracy

There are several possible sources of error to our bioenergetics model. Amongst those, the allometric equation chosen to estimate daily energy requirements is probably the most important one. The equation we used is specifically indicated for seabirds in warm water regions, as is the case of the Selvagens islands (summer SST often around 22°C, own data). Other available equations seem to

Table 3 Estimated numbers of each seabird prey species that adult Yellow-legged Gulls must ingest to meet their energetic needs during the breeding season

Species	% of (FMR)	Total number of individuals consumed (12 pairs/3.5 months)	Number of individuals consumed per gull/month
Bulwer's Petrel (ads)	8.1	293	3.5
(chicks)	0.9	28	0.3
(eggs)	0.1	14	0.2
Cory's Shearwater (eggs)	9.0	307	3.7
Macaronesian Shearwater (chick)	0.6	14	0.2
Band-rumped Storm-petrel (ads)	5.8	475	5.7
White-faced Storm-petrel (ads)	55.3	4,079	48.6
(chicks)	1.1	70	0.8
(eggs)	0.1	28	0.3
Total number of seabirds consumed (ads)	69.2	4,847	57.8
(chicks)	2.6	112	1.3
(eggs)	9.2	349	4.2

Total numbers include the energy spent to attain a breeding success of 0.25 (see "Materials and methods" section). On the first column the percentage of the total energy requirements (FMR) fulfilled by each prey type is presented overestimate considerably FMR; for example, equation 26 in Nagy et al. 1999 for "all seabirds" (FMR=kJ/day=14.25 (gbodymass)$^{0.659}$) yields almost the same FMR value as another equation that is specifically designed for cold water seabirds (kJ/day=15.6 (gbodymass)$^{0.646}$; Birt-Friesen et al. 1989), with the resulting FMR being almost twice as high as for warm water seabirds. Gulls breeding in the Selvagens are exposed to very different climate conditions from the ones in northern Europe, and so the energetic costs of thermoregulation should be minimal (e.g., Piersma 2002). Therefore, our estimate for FMR is probably reasonable.

Secondly, our diet sampling method might have underestimated fish consumption. Fish is a major component of the diet of large gulls in many colonies (e.g., Spaans 1971). The absence of fish in pellets could be due to the fact that this item is mostly fed to chicks, as they have higher digestion efficiency than adults (e.g., Spaans 1971). It is also well known that prey containing parts that are easy to digest can be underestimated when pellets are used to assess diet (see, for example, González-Solís et al. 1997 and references therein; Votier et al. 2001). Nevertheless, pellets are often used to study the diet of gulls and related species (Barrett et al. 2007) and fish bones and otoliths from a wide range of species can generally be found and identified in those analyses. Hence, our failure to find fish remains in pellets strongly suggests that fish are relatively unimportant as food for nesting gulls on Selvagem. Furthermore, fish offal, which is not detectable in pellets, seems to be almost non-existent around the Selvagens.

Despite the above considerations, it is possible that our study gulls did consume some fish that went unnoticed in dietary analyses. If fish is arbitrarily considered to represent 30% of all ingested food, the number of consumed seabirds would be reduced by approximately 46%, which would represent a significant change. However, this possibility would still not challenge our conclusions about the importance of seabirds for gulls in the Selvagens and the potential of gulls to impact prey populations.

Predation on seabirds

The number of adult White-faced Storm-petrels estimated to have been predated by gulls (4,079 birds; Table 3) is equivalent to approximately 6% of the breeding population (about 72,000 adults; Campos and Granadeiro 1999). This should not be seen as an accurate estimation of mortality rates caused by gulls on the breeding petrel population, but rather as an estimate of the broad level of predation. It is not clear whether such predation might influence population dynamics but, as adult petrels have typically very low annual mortality rates (3-8%), an increase as small as 2-3% is potentially of significant impact. It is likely that a considerable percentage of the preyed petrels would have been prospecting immatures and non-breeding adults (e.g., Morse and Buchheister 1977; Phillips et al. 1999; Oro et al. 2005; but see Stenhouse and Montevecchi 1999), which would alleviate the demographic impact of this predation pressure. Also, the number of adults in gull diet may have been inflated because pre-fledging chicks or fledged juveniles were included in the same category. On the other hand, we did not consider non-breeding gulls in our model (as their diet is almost unknown) and they are likely to prey over petrels as well. Furthermore, gulls may also predate petrels during the winter (from December to March), a period which was not taken into account in our studies and models.

Our data indicate that gulls will also consume Cory's Shearwater eggs (Table 3) but, according to our observations, those are mainly neglected or abandoned eggs (as already suggested by Mougin and Stahl 1981). This and the fact that the population of this shearwater is increasing steadily in numbers (Granadeiro et al. 2006) makes this a phenomenon of lesser concern.

Except for White-faced Storm-petrels and Cory's Shearwaters, there are no population estimates for other breeding petrels on Selvagem Grande creating difficulties in assessing the impact that gull predation may cause. Even in the absence of that information, predation levels over Band-rumped Storm-petrels, as estimated through our model (Table 3), can be important and deserve more research.

Despite the fact that gulls take large numbers of petrels, such predation may be normal in this area as indicated by the long-term coexistence of gulls and other seabirds on the Selvagens. At the present population size, gulls may act only as a normal part of a complex ecosystem removing less fit individuals of other species as probably happened for thousands of years with no real deleterious consequences for the survival of prey populations (see Swennen 1989; Oro et al. 2005; Oro and Martínez-Abraín 2007).

Possible trends and management implications

More than 100 years ago, Ogilvie Grant (1896) reported the same approximate number of breeding gulls that exists in the present on Selvagem Grande, and more recent observations reflect a broadly stable population. Some higher figures reported (Zino 1971; Jouanin 1974) may include immature individuals as these estimates fail to differentiate non-breeders and breeders. This stability in numbers through the years may result from a combination of various factors. Nests (and even some adults) were often destroyed during the 1990s and even more recently some nest control has taken place. Nevertheless, breeding success seems to be naturally low, which may result from low food availability. On the other hand, juveniles and even adult gulls are scarce on the Selvagens during autumn, which indicate that they move elsewhere. Likely destinations may be the Canaries and Madeira, areas where gull populations have known periods of population growth recently (e.g., Rodríguez et al. 2003). As such, these areas may provide good feeding resources, which might support a population growth in the Selvagens through improved juvenile and adult overwinter survival.

Population growth rates of 7-16% per year have been reported elsewhere for Yellow-legged gulls (e.g., Duhem et al. 2008; Morais et al. 1998) and even higher rates are known for other large gulls (20-25% per year; Harris 1970). If the Selvagens population was to increase at only 10% per year, it would take just 6 years to reach 20 pairs, which would (according to our model) potentially be able to take the equivalent to 10% of the estimated White-faced Storm-petrel breeding population each year. Such a level of predation would probably be unsustainable.

Gull population increases driven by human waste availability may unbalance stable predator-prey systems. This type of situation has been documented many times elsewhere (e.g., Vidal et al. 1998). A frequent response by managers is to implement population control programs in order to restrict the total number of breeding gulls and/or to eliminate specific individuals that specialize with greater efficiency in seabird predation. Such efforts raise several issues, such as those related to the efficiency of control measures or to concerns related to animal welfare (for a discussion of several aspects related to these, see Ickes et al. 1998; Bosch et al. 2000; Guillemette and Brousseau 2001; Votier et al. 2004; Oro et al. 2005; Oro and Martínez-Abraín 2007). In the case of the Selvagens, any control at early stages would involve only a reduced number of individuals, which would not imply large operational costs or any serious risks of an increase in emigration with impacts to be felt elsewhere. Furthermore, a control effort before any population increase could target only eggs, thereby reducing concerns over negative impacts on animal welfare.

We suggest the Selvagens gull population should be closely monitored so that demographic changes can be detected before important shifts in numbers can take place. Ideally, prey populations should also be monitored, but this is difficult, as there are no practical and accurate census methods that are sensitive enough to detect minor or moderate population declines in small petrel species such as the ones that occur in our area. The development of detailed demographic models for prey populations, whilst highly desirable, may also be difficult to achieve. In the absence of information allowing an accurate prediction of the "acceptable breeding numbers" of gulls that the Selvagens may support, a precautionary approach may be warranted. Managers of the reserve could consider resuming the systematic destruction of gull clutches as soon as there is evidence that gull numbers start increasing.

In conclusion, presently the small breeding population of Yellow-legged Gulls may not represent an immediate threat to burrowing petrels on the Selvagens archipelago. An indication that petrels possibly tolerate this level of predation is that gull numbers have remained broadly stable for more than one century and yet petrel populations have remained large. However, accurate censuses and continuous close monitoring of the gull and petrel populations are necessary to detect changes to this situation.

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