

Black Brant *Branta bernicla nigricans* grit acquisition at Humboldt Bay, California, USA

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Abstract

The Black Brant *Branta bernicla nigricans* is a seagrass-obligate goose, strongly tied to the estuaries of the Pacific Flyway coast of North America. Black Brant are unique in that they remain reliant on their traditional food resource, in contrast to other Brent Goose populations that now readily switch to feed on agricultural land during migration and in winter. While Black Brant use of coastal estuaries within the Pacific Flyway is determined mainly by the presence of Common Eelgrass *Zostera marina*, accessible grit sites are a second, often overlooked, yet essential requirement that may be in part responsible for stop-over duration within these coastal estuaries. This paper synthesises existing literature and presents previously unpublished data from a series of studies conducted at Humboldt Bay, California, describing the role and importance of grit sites to Black Brant. We found that the local environment influences gizzard grit composition and, although evidence for grit selectivity by Brant makes it challenging, it is possible to link a Brant's current gizzard contents to a previously used bay or grit site. The interval between successive sightings of ringed individuals identified at the primary grit site varied (mean \pm s.d. = 8.6 ± 9.6 days, range = 4.5–10.1 days). We suggest that, during spring staging, individual geese must weigh trade-offs of time spent taking grit with time lost for other activities – including foraging.

Key words: Black Brant, estuaries, eelgrass, gizzard, grit, grit sites, Pacific Flyway, restoration, sandbars.

Grit is a physiological requirement of avian herbivores (McCann 1961; Moore 1999), and grit particles are accumulated in the

gizzard where food is ground for further digestion. The resultant digestive efficiency is related to the amount, type and size of the

grit particles (Skead & Mitchell 1983; Moore 1998) and failure to maintain gizzard grit results in reduced digestive efficiency and body condition (McCann 1939, 1961, Ebbing & Spaans 1995). Grit retention in the gizzard is also influenced by the type and size of the grit particles, characteristics of ingested food, and the rate of ingesting additional grit (Trost 1981; Goinfriddo & Best 1999; VerCauteren *et al.* 2003). Long-distance migrants, such as Black Brant *Branta bernicla nigricans*, are faced with the decision to either carry gizzard grit or replenish it at suitable gritting sites at stopover locations during migration. Even when suitable grit substrate is abundant, access may be limited by environmental conditions, including human activity at the site (Lee *et al.* 2004; Moore & Black 2006a; Bjerre 2007).

In the southern part of Humboldt Bay, where Black Brant forage on California's largest expanse of eelgrass (Common Eelgrass *Zostera marina*; Moore *et al.* 2004), there are approximately six gritting locations (Henry 1980; Lee *et al.* 2004). Studies at Humboldt Bay have shown that Black Brant favour the eelgrass beds closest to their gritting sites (Moore & Black 2006a), and that they adjust gritting activity according to tidal fluctuations (Lee *et al.* 2004; Bjerre 2007). Granular analysis of Black Brant gizzards, which found evidence for strong selection of certain particle sizes (Lee *et al.* 2004; Bjerre 2007), and particle colour (which reflects grit composition), may indicate the direction of Black Brant migration, as grit taken at one staging site is carried by the bird to the next (Lee *et al.* 2004).

In the current study, we present information on grit composition and grit site visitation intervals to build a better picture of these birds' requirements for grit. Our objectives were to: 1) document the content of Black Brant gizzards obtained from Humboldt Bay for comparison with other bays used by the geese along the flyway, to determine whether this was a suitable method for assessing the relative use of staging sites by Black Brant, and 2) describe intervals between Black Brant visits to the primary grit site in southern Humboldt Bay to explore general patterns, timing and variability of grit site use. Additionally, we consider the management implications of protecting grit sites and for improving the definition of habitat suitability for Black Brant staging sites.

Methods

Humboldt Bay, California, USA (40°48'N, 124°07'W; Fig. 1) experiences mixed semi-diurnal tides, with two low tides and two high tides of variable heights occurring each day, limiting the amount of time that both gritting sites and eelgrass beds are available (Moore & Black 2006a; Elkinton *et al.* 2013; Fig. 2). Black Brant at Humboldt Bay predominantly use grit sites on the ebb tide (falling tide), typically between 0.5–1.8 m (relative to the Mean Lower Low Water; MLLW), arriving at the grit site shortly before the first eelgrass beds become available at ~0.9 m MLLW (Lee *et al.* 2004; Moore & Black 2006a; Bjerre 2007). The majority of gritting sites are located along the shoreline of the South Spit, the physical dune barrier that separates the bay from the Pacific Ocean (Fig. 1). However, Lee *et al.*

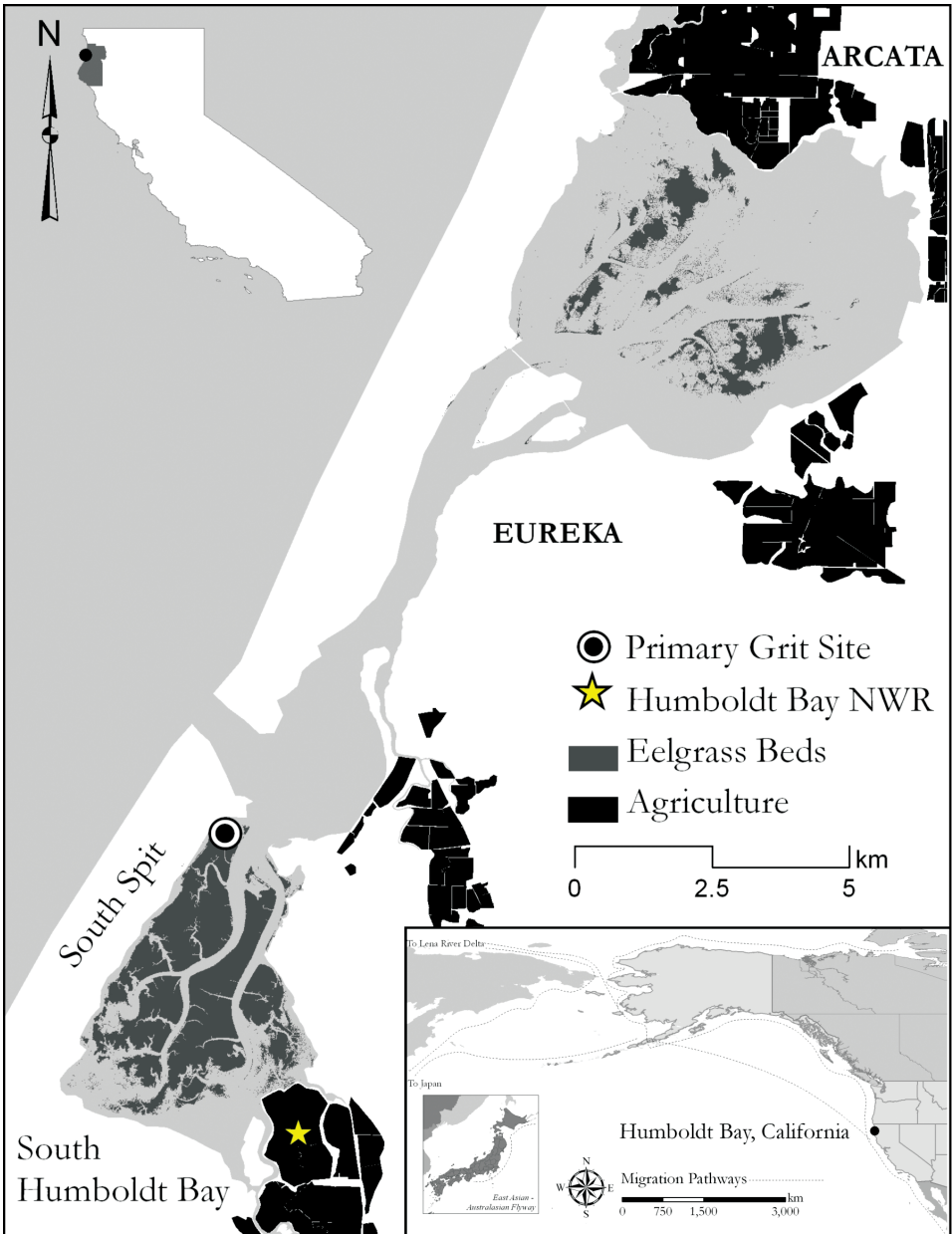


Figure 1. Map of Humboldt Bay, California, USA showing the primary grit site location in relation to eelgrass beds and surrounding agricultural lands. The majority of Black Brant use occurs in southern Humboldt Bay where grit sites are located along the western shoreline referred to as the South Spit.

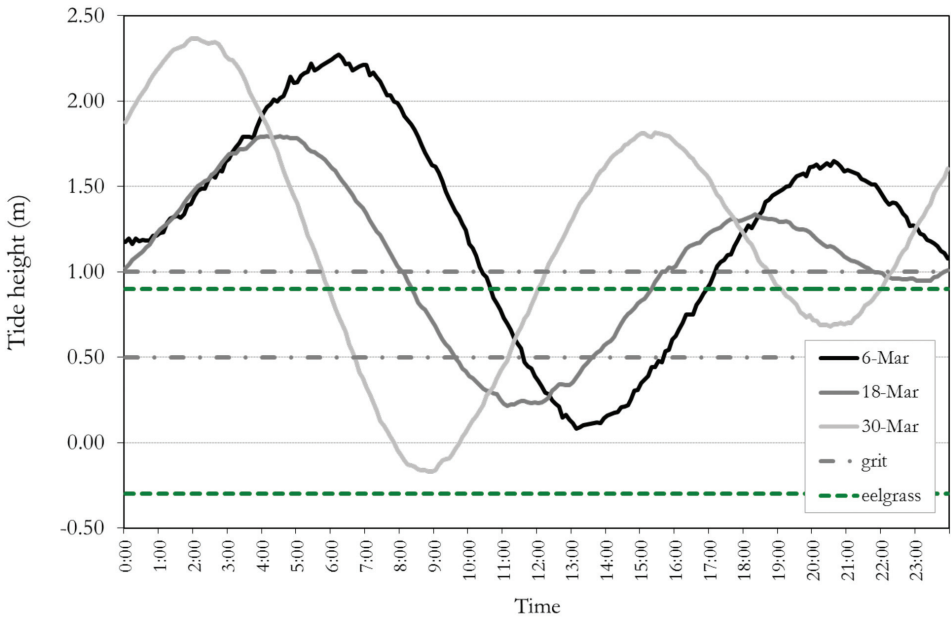


Figure 2. Three examples of daily mixed semi-diurnal tides at Humboldt Bay, California, during March 2013, relative to Mean Lower Low Water tidal datum. Dashed lines represent windows of preferred grit site availability (0.5–1.0 m) and the exposure to lower limit of available eelgrass beds (<math>< 0.9\text{--}3\text{ m}</math>) in southern Humboldt Bay.

(2004) showed that three particular sites accounted for 78% of all Black Brant use in southern Humboldt Bay, with one primary site accounting for more than all the others combined.

Grit composition analysis

Grit site samples were obtained from five known Black Brant staging areas along the Pacific Flyway by collaborators familiar with each particular bay's gritting locations (Fig. 3). One sample was collected at each grit site, the primary site for each respective bay, during spring migration. Each sample was later sieved to isolate 0.5–1.0 mm size particles, targeting the range of selected grit particle sizes (Bjerre 2007), for further

preparation. Permission was obtained from the Bureau of Land Management to set up a voluntary hunter check station, where hunters donated 16 gizzards from Black Brant shot from the South Spit at Humboldt Bay during the youth hunt held on 30 January 2004. Each grit site and gizzard sample was stored in a separate, individually-labelled, sealed bag and stored in a freezer until further processing.

Grit site and gizzard sample contents were placed into individual crucibles, and burned in a kiln at 500°C for 2 h (B. Burke, pers. comm.) to remove any organic matter (*i.e.* eelgrass) and thus produce pure rock and mineral samples. Thin section slides were created from three of the five grit-site

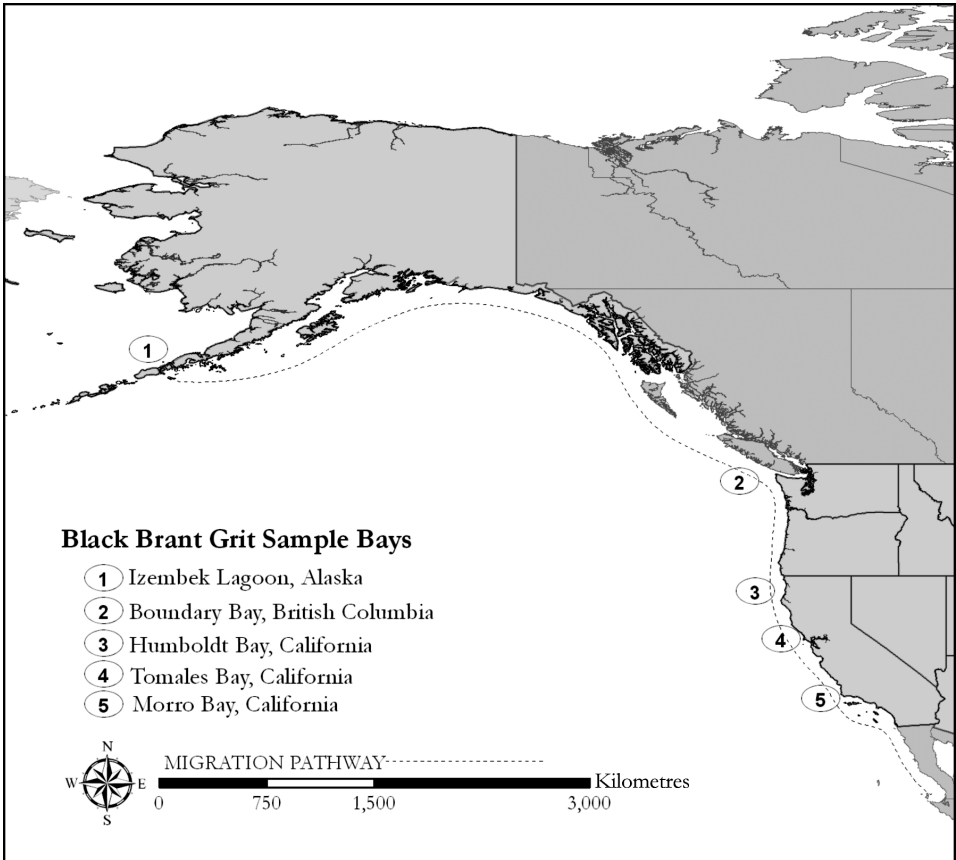


Figure 3. Black Brant staging bays for which a gritting site sample was obtained. Thin-section slides were created for samples from Izembek Lagoon, Boundary Bay, and Humboldt Bay. Black Brant gizzard content samples were obtained from Humboldt Bay.

samples and two of the 16 gizzard samples by the Humboldt State University Geology Department; the time required to prepare each sample (see below) limited the number of slides available for analysis. The difference in the way a rock or mineral grain refracts cross-polarized light from the microscope gives clues to its formation (*e.g.* volcanic, or formed by extrusive or intrusive forces) and aids in identification. All thin

section slides were analysed for rock and mineral composition using a count system similar to the Gazzi-Dickinson method (Dickinson 1970). The field of view was focused on the centre of the slide, contained a minimum of 50 fragments, and was analysed with a microscope at 100× total magnification, through cross-polarized light, to quantify the different percentages of rock and mineral fragments present in each grit

site and gizzard sample. This was a time-intensive process (~24–48 h per slide from preparation to creation), but permitted a rigorous composition analysis of the rock and mineral content not possible with the naked eye, perhaps leading to the identification of unique geologic signatures for each bay in the Pacific Flyway. Comparisons between samples were tested using a chi-squared test, using the different grit site samples (from the surrounding landscape) as the expected values, and Black Brant gizzard samples as the observed values; we used the composition percentages derived from the microscopic analysis in each case.

Crude resight interval

We made crude estimates of the intervals between visits to the grit site by individual geese, by analysing sightings of leg-ringed birds collected during a study of spatio-temporal use of grit sites by Black Brant (Bjerre 2007). Plastic leg-rings, each engraved with a unique code, were read using a 60× spotting scope from a blind on the bay-side shore of South Spit, where Black Brant could be observed at their primary South Bay grit site (as identified by Lee *et al.* 2004). To standardise the timing of observations in relation to the tide, all observations were made during ebbing tides, from January–May (encompassing the spring staging period at Humboldt Bay) on 54 and 46 days in 2002 and 2003, respectively. Individuals had been marked with leg-rings by collaborators at major breeding and moulting locations; as a result, ~8% of the population was marked at the time of the study (Sedinger *et al.* 1993;

Ward *et al.* 1993; Bollinger & Derksen 1996). We determined the average (\pm s.d.) and range of intervals (in days) between re-sightings of individual geese, using a combined 2002 and 2003 dataset; the data were statistically similar for 2002 and 2003, and were pooled to improve sample size.

Results

Grit composition

All grit site and gizzard samples contained five different types of sand-sized fragments, including: quartz (both volcanic and non-volcanic), chert, lithic fragments (rock fragments), clinopyroxene, and plagioclases (Fig. 4). Unique rock or mineral fragments were not observed in any of the grit site bay samples, which would have provided a unique signature for the identification of particular Pacific Flyway bays or estuaries; however, variation in the fragment composition of the samples was sufficient to permit a comparison (Table 1). The two gizzard-content samples (from spring migrants) were significantly different in composition when compared to the three northern grit site bay samples of Humboldt Bay, Boundary Bay, and Izembek Lagoon (Brant 1: $\chi^2_4 = 38.37$, $P < 0.001$, $\chi^2_4 = 168.48$, $P < 0.001$, $\chi^2_4 = 66.43$, $P < 0.001$, and Brant 2: $\chi^2_4 = 35.61$, $P < 0.001$, $\chi^2_4 = 134.12$, $P < 0.001$, $\chi^2_4 = 57.41$, $P < 0.001$), but were similar in composition to each other (Table 1).

Crude resight interval

A total of 1,917 ring sightings were recorded for 1,303 different individuals

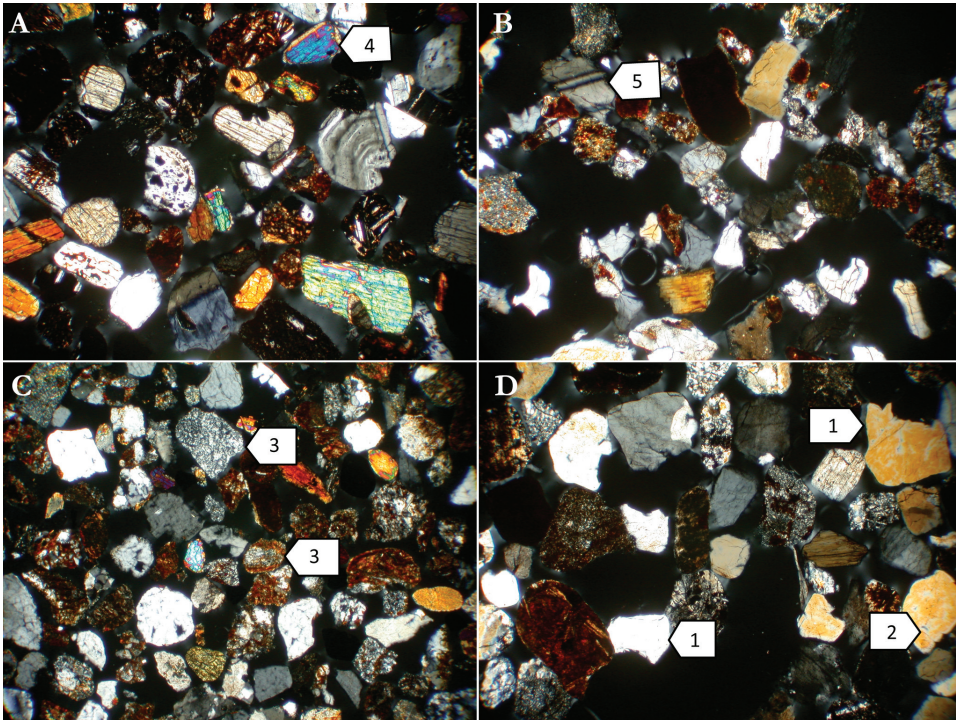


Figure 4. Grit thin-section slides as viewed under cross-polarized light using a microscope. Images shown are for: A) Izembek Lagoon, B) Boundary Bay, C) Humboldt Bay, and D) gizzard content from a hunter-shot Black Brant. Labels indicate representative examples of quartz (D1; yellow and white), chert (D2; grey spots), lithic (rock) fragments (C3), clinopyroxene (A4; colourful), and plagioclase (B5; striated).

identified during the 100 grit-site observation days in 2002 and 2003. A total of 278 individuals were observed at the primary grit site more than once in a given year. Ten or more individuals were identified on 60% of the observation days, 5–10 individuals were present on 24% of occasions and < 5 individuals were present on 16% of occasions. The average interval between ring resightings was 8.6 ± 9.6 days ($n = 278$) with a range of 1–60 days (Fig. 5); we recorded 1,025 individuals at the grit site only once.

Discussion

There has long been an understanding of particular connections between waterfowl and specific grit sites. For example, shore-blinds along the South Spit of Humboldt Bay have traditionally been used by hunters to harvest Black Brant, a regionally prized game bird, due to the reliability of birds returning to distinctive points along this shoreline (Denson 1964; Henry 1980). During the mid 1980s, introduction of protection measures (*e.g.* refuge formation)

Table 1. Percentages of rock and mineral fragments found in two gizzard samples collected at Humboldt Bay, California on 30 January 2004, and in three samples collected at bays used by the birds for gritting between 30 January 2004 and 15 November 2004. Percentages were corrected to account for empty space between fragments present in thin-section slide analyses.

Fragments present	Brant gizzard samples		Grit site samples		
	Brant 04	Brant 14	Humboldt Bay, California	Boundary Bay, BC, Canada	Izembek Lagoon, Alaska
Quartz	48.8	53.8	32.3	12.0	7.1
Chert	12.2	10.8	24.2	9.6	42.9
Lithic fragments	36.6	32.2	24.2	66.3	21.4
Clinopyroxene	2.4	1.6	16.1	6.0	14.3
Plagioclase	0.0	1.6	3.2	6.0	14.3

and a reduction in disturbance (*e.g.* changes in hunting season regulations) helped increase previously suppressed abundance levels of Black Brant using Humboldt Bay (Henry 1980; Moore & Black 2006b). Some recognition was given to the detrimental impacts of disturbance within the eelgrass beds and also at grit site locations along the shore (Henry 1980), with additional studies in more recent years supporting these findings (Schmidt 1999; Bjerre 2007).

Nearly 30 years ago, in developing a habitat suitability model for Black Brant, Schroeder (1984) identified two variables as requirements for optimal habitat: 1) having $\geq 90\%$ coverage of useable eelgrass, and 2) having $\geq 10\%$ of the shoreline containing isolated sand bars or sandy beaches, described as being necessary for preening, resting and obtaining grit. Though the

model acknowledges the necessity for grit sites, one potential weakness with this simplified model of site suitability for Black Brant is the inability to account for the complexity of eelgrass and gritting site availability relative to an estuary-specific tidal frame.

Grit composition has been noted to change based on the direction of Black Brant migration, with gizzard grit being blacker in colour in hunter-donated samples from birds migrating south from Alaska and whiter in colour when migrating north from Mexico (Lee *et al.* 2004). This supports findings in other studies that found gizzard grit composition to be highly influenced by local grit characteristics, such as size of available grit (Goinfriddo & Best 1999; VerCauteren *et al.* 2003). The grit composition analysis presented here helps

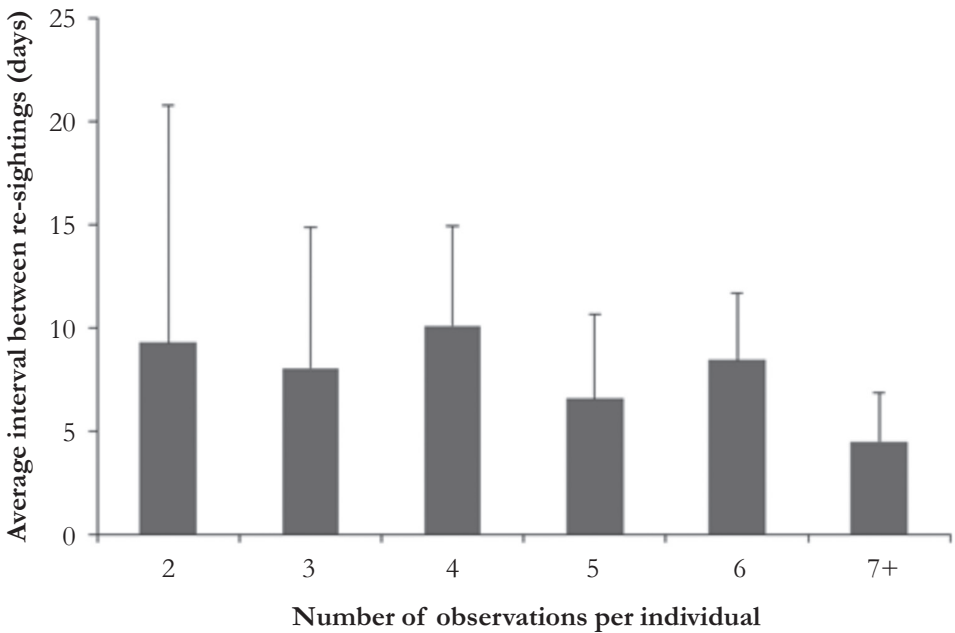


Figure 5. Average interval (in days, \pm s.d.) between re-sightings of individually-marked spring-staging Black Brant at the primary grit site in South Humboldt Bay, California. The basic re-sightings intervals presented do not account for observation probabilities.

to demonstrate that each bay indeed has a unique rock and mineral fragment composition, and that analysis of the contents of Black Brant gizzards may indicate, from their composition, grit sites recently used by the birds. However, identification of specific bays may be complicated by variability in Black Brant grit retention rates and particle selection. Future research would benefit from the inclusion of Black Brant gizzard content samples from a range of bays where grit site samples were collected. Without inclusion of grit samples from bays along the full extent of staging sites, it is difficult to infer if elevated quartz in gizzard samples indicate selection for quartz at Humboldt Bay, or retention of

quartz from sites that have higher quartz composition (e.g. bays and estuaries of Baja California, Mexico).

Previous analyses of grit particles within Black Brant gizzards found a strong selection of the largest but rarely available particle size classes (0.5–1.0 mm), while also including medium-sized particles (0.25–0.5 mm) that are more readily available at gritting sites (Lee *et al.* 2004; Bjerre 2007). Though it remains unclear if selectivity for larger grit is entirely behaviourally-based or partially a physiological selection occurring in the gizzard, Bjerre (2007) found evidence that Black Brant do favour areas within the grit site with larger grit particles and specifically pick up grit in the best spots in

spite of trade-offs with foraging time. Questions linger about how the interaction between grit composition and grit site availability may relate to the rate at which birds return to the grit site, and the direct costs or benefits that may result from different individual return-interval strategies for a specific grit site.

The re-sightings data indicate that Black Brant return to their main grit site on average every 8.6 days or, likely, more frequently as not all individuals are observed on every sighting attempt. The mean return interval ranged from 4.5–10.1 days and appeared shorter and less variable for individuals observed more often, despite fewer individuals being observed in each subsequent re-sighting-frequency category. This may reflect individual differences in detection probability rather than true differences in intervals between visits to the grit site. Brant using Humboldt Bay for extended periods may return more predictably to replenish grit, compared with birds passing through the area which may be less familiar with patterns of grit availability or more inclined to maximise foraging time. The true “visitation interval” to the grit site is likely to be more frequent; accounting for detection probability of individuals and excluding transient birds in future analyses would provide a more robust estimate of the interval between grit site visits. Due to the migratory turn-over rate in Humboldt Bay (Lee *et al.* 2007; Black *et al.* 2010), especially in March or April, many birds pass through Humboldt Bay quickly with a low probability of being detected at the grit site. These transient individuals leave for subsequent stop-over sites (and other grit

sites) before there is a second opportunity to observe them at the primary grit sites at South Bay.

Conservation and restoration implications

The location of grit sites within the Pacific Flyway estuaries used by Black Brant need to be evaluated for threats imposed by development and other human disturbance, and to receive the same level of protection and emphasis as is placed on eelgrass beds. For example, at Humboldt Bay there has been an increase in water-based recreational activity (*e.g.* kayak water-trails) that will demand attention (Prop & Deerenberg 1991). Furthermore, other Pacific Flyway estuaries that are known to have once supported Black Brant should be assessed for the presence of, or the potential for grit site (sand bar) restoration to encourage re-expansion of Black Brant into these bays and estuaries.

With increased uncertainty posed by sea-level rise scenarios and the site-specific consequences that must be considered (*e.g.* tidal range, sediment accretion rates, tectonic uplifting, *etc.*), estuaries used by Black Brant need to be evaluated for potential future conditions. Shaughnessy *et al.* (2012) demonstrated changes over 100 years in eelgrass distribution under predicted rates of fine sediment inflow, plate tectonic movement, and sea-level rise within several Pacific Flyway estuaries, but did not consider potential movement of adjacent sand dunes which influence sand bars or grit sites. In order to predict changes in the Black Brant’s range and distribution among bays and estuaries, models should

include characteristics of grit sites (*e.g.* tidal elevation, slope and aspect, distance to eelgrass, and disturbance levels) because of their role in facilitating the breakdown and digestion of foods. This is important because it is unlikely that a bay or estuary with ample eelgrass could service Black Brant if gritting opportunities were not also available.

Recommendations and research needs

We recommend that the following tasks be undertaken to establish base-line information related to Black Brant staging site requirements within the Pacific Flyway: 1) document the location and size of all sandbars used and preferred by Black Brant, 2) if bathymetry and tidal data are available, calculate the tidal range for which those sandbars are available to Black Brant, especially in relation to the window of availability for eelgrass foraging, 3) identify constraints to those grit sites posed by development and disturbance, and 4) predict changes to these sites over time with projected sediment and tectonic movements, and sea-level rise.

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