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INVASION NOTE

Range expansion of nonindigenous caribou in the Aleutian archipelago of Alaska

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Abstract Caribou (*Rangifer tarandus*) are nonindigenous to all but the eastern-most island of the Aleutian archipelago of Alaska. In 1958–1959, caribou were intentionally introduced to Adak Island in the central archipelago, and the population has at least tripled in recent years subsequent to the closure of a naval air facility. Although dispersal of caribou to adjacent islands has been suspected, no historical documentation has occurred to date. Herein, we report consistent detections of caribou sign on the adjacent island of Kagalaska over 2 summer field seasons (2010–2011), and visual detection of caribou on that island during the summer of 2011. Ecological impacts of caribou on Kagalaska are not strongly apparent at the present time and we do not know how many animals permanently occupy the island. However, establishment of a reproductively viable resident population on Kagalaska is worrisome and could set the stage for a step-wise invasion of additional nearby islands.

Keywords Dispersal · Immigration · Emigration · Invasive · Ocean crossing · Reindeer · Swim

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Introduction

Non-native mammalian herbivores have been introduced on numerous oceanic islands throughout the globe (Courchamp et al. 2003). Once established, these animals become invasive as they rapidly exploit island resources due to the lack of co-evolved defenses by island flora, a paucity of intra-guild competitors, and the absence of top-down control by native predators. However, the ecological damage inflicted by the invasive species can remain localized to a single island as long as barriers to immigration to nearby islands exist, and the species has limited dispersal capabilities. Accordingly, life history traits coupled with landscape characteristics contribute to a species' invasiveness (Kolar and Lodge 2001).

The Aleutian archipelago of Alaska comprises a chain of over 400 oceanic islands extending 1,800 km westwardly from the southwestern tip of mainland Alaska towards Asia. Most islands are part of the

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Alaska Maritime National Wildlife Refuge (AMNWR), and all but the eastern-most islands of the chain are devoid of indigenous land mammals. However, introductions of caribou (*Rangifer tarandus*) and their domesticated reindeer counterparts occurred on several large islands, including Unalaska, Umnak, Atka, and Adak during the early and mid twentieth century (Swanson and Barker 1992; Ebbert and Byrd 2002) (Fig. 1). In the case of Adak, 23 barren-ground caribou (*R.t. granti*) were transplanted from mainland Alaska in 1958–1959 at the request of the US Navy in order to provide recreational hunting opportunities and an emergency food supply for military personnel (Jones 1966). The resulting population steadily grew to a size of <1,000 animals until the naval facility was decommissioned in the early 1990s. A combination of the lack natural predators, relatively mild maritime climate, and dramatic decline in hunter harvest rates due to closure of the naval facility likely contributed to an increased herd size of at least 2,800 animals by 2005 (Williams and Tutiakoff 2005). No systematic population surveys have been conducted since that time, yet our field observations indicate the herd has continued to grow with no apparent signs of a population crash characteristic of other islands with introduced *Rangifer* (i.e., Tyler 2010).

Caribou are exceptionally good swimmers. Mainland populations will routinely cross wide rivers and lakes during the course of annual migrations (ACIA 2004), and caribou in the high Canadian arctic will traverse ice-free oceanic straits separating islands and the mainland (Miller 1995). Nevertheless, swimming across cold, swift waters can be risky for caribou as drowning deaths are known to occur, particularly among young calves (Kendrick and Lyver 2005). Inter-island movements by the Adak caribou herd are likely constrained to some degree by oceanic straits separating islands characterized (at worst) by strong tidal currents in excess of 11 km h^{-1}, standing-waves, and treacherous shorelines. However, distances between Adak and adjacent islands to the east are relatively short (ca. 2 km), and caribou do swim between small islets in protected bays on the west side of Adak. Hence, dispersal to adjacent islands has been suspected but not documented unequivocally during the recent period of rapid herd growth (Williams and Tutiakoff 2005). Establishment of viable caribou populations on large islands adjacent to Adak would pose additional challenges for the management of insular maritime tundra ecosystems invaded by this introduced ungulate. Herein, we report recent evidence of inter-island movements by Adak caribou to the adjacent island of Kagalaska, and discuss its ecological and management implications.

Methods

Adak is a large (725 km^2) mountainous island located in the Andreanof group of the central Aleutian archipelago (Fig. 1). Kanaga is the next largest island located over 15 km to the west. Kagalaska is the closest large (116 km^2) island to the east and is separated from Adak by Kagalaska Strait, which is roughly 1.0 km wide on average and only 400 m wide at its narrowest point. Notably, Adak has a mixed land ownership pattern, whereby the northern end is owned by a native corporation and harbors a small (<100 person) community while the remainder of the island lies within the AMNWR. All of Kagalaska is exclusively owned by the AMNWR and has no human habitation. The climate and floristic community of the Aleutians are characteristically maritime. Summers are cool (5–10°C), wet, and foggy, whereas cyclonic storms occur frequently during winter but temperatures hover near 0°C. Importantly, oceanic waters remain ice-free year round. Treeless maritime tundra comprises the vegetation community, which includes coastal and alpine grass–forb meadows, dwarf shrub and lichen dominated heaths, and windswept fellfields. The plant growing season is relatively short and occurs primarily from June to September.

We conducted extensive sampling of vegetation and soil characteristics on Adak and Kagalaska during July–August, 2010–2011 as part of a broader study designed to quantify caribou impacts on ecosystem processes. Kagalaska was selected as a reference island and assumed to be 'caribou free' since no historic record of a Kagalaska caribou herd exists. To provide a measurable index of caribou use intensity, we counted the number of caribou fecal pellet groups encountered along randomly placed 400-m long transects on both islands in both years. We used Fisher exact tests to determine if the odds of detecting caribou pellet groups along transects differed between islands. In addition, we required additional information to determine the extent (if any) of caribou

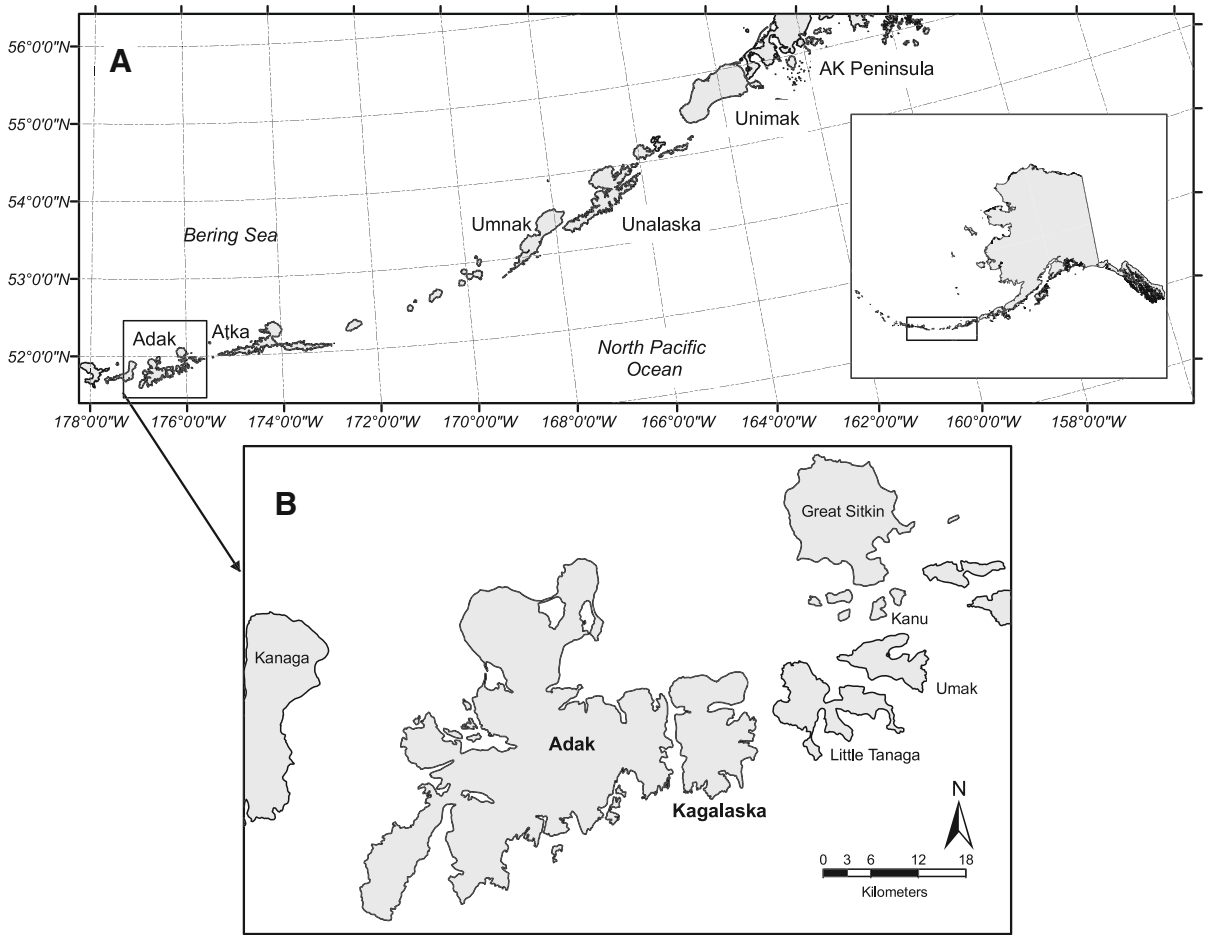

Fig. 1 **a** *Map* of the Aleutian archipelago of Alaska illustrating islands with native (Unimak) and introduced (Unalaska, Umnak, Atka, Adak) *Rangifer* populations, **b** *inset map* illustrating spatial arrangement of islands near Adak

occupancy of Kagalaska in order to validate its use as a true 'caribou-free' control in the study. Thus, we visually scanned the landscape on Kagalaska for the presence of caribou during and between transects, and recorded the location and type (i.e., fecal pellet group, track, grazing marks) of all sign when encountered.

Results

Caribou sign encounters

We detected caribou sign on Kagalaska during systematic transect surveys as well as during the course of traversing the island. However, the odds of encountering at least 1 fecal pellet group along transects were 19 times higher on Adak compared to Kagalaska ($P < 0.0001$). Fecal pellet groups were encountered on only 3 out of 27 transects on Kagalaska compared to 66 out of 121 transects on Adak. Moreover, each transect detection on Kagalaska consisted of a single fecal pellet group, whereas an average of 18.9 pellet groups per transect were detected on Adak.

An equivalent number of days (5) were spent surveying Kagalaska each summer. We encountered fecal pellet groups at 3 locations and single track-sets at 2 locations while traversing the central portion of Kagalaska during 2010 (Fig. 2). We detected sign more frequently during 2011, which included fecal pellet groups at 5 locations, single track sets at 11 locations, and grazing marks at 3 locations while traversing the northwestern and south-central portion of the island (Fig. 2).

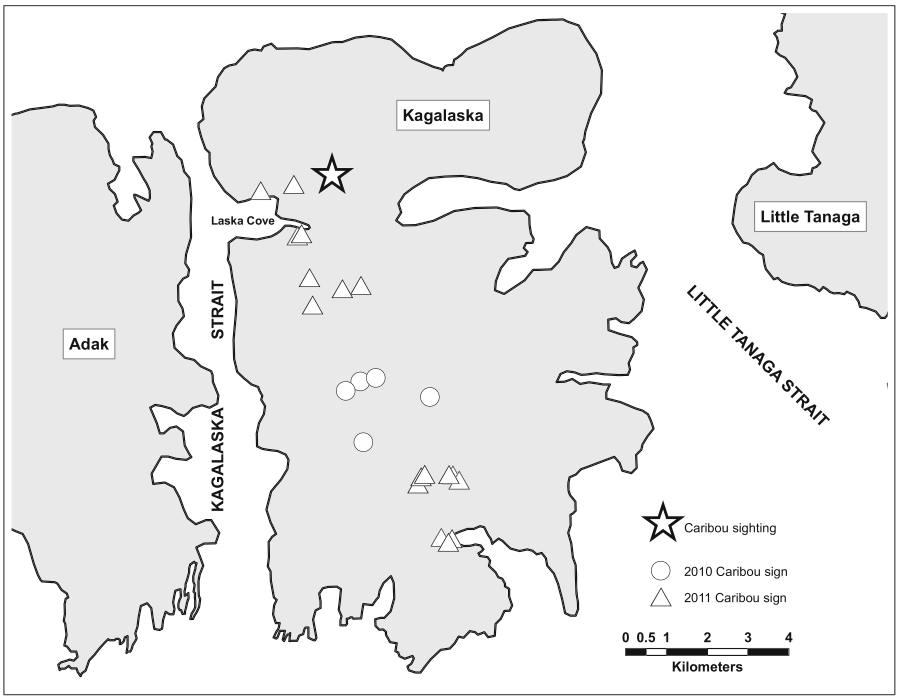

Fig. 2 Spatial distribution of caribou observations and sign detections (fecal pellet groups, tracks, grazing marks) on Kagalaska Island during July–August, 2010, 2011

Confirmed visual observation

Caribou were not visually observed during the summer of 2010. However, on 15 August 2011 at 1610, we spotted four adult caribou while conducting vegetation sampling in a watershed draining into Laska Cove on the northeastern side of Kagalaska (51.83952°N, 176.37863°W) (Fig. 2). The group was walking briskly approximately 450 m away from our location. Three of the four animals were clearly large-bodied adult males with stout, multi-pointed antlers. The remaining animal was notably smaller, and could not be confidently sexed based on antler presence since both male and female caribou have antlers during late summer. We were only able to observe the group for <1 min before a fog bank completely obscured visibility and negated any chance to positively identify the gender of the smaller animal.

Discussion

Caribou have been suspected of swimming to Kagalaska since the late 1990s, when a few cast antlers were detected on the island during fox eradication efforts (Williams and Tutiakoff 2005). Nevertheless, repeated detections of caribou sign over 2 annual sampling efforts that covered multiple areas of the island coupled with a confirmed sighting of caribou has never been documented on Kagalaska until now. *Rangifer* introductions have occurred on islands in North Pacific-Bering Sea, North and South Atlantic, and South Indian Ocean (Swanson and Barker 1992; Leader-Williams 1988; Tyler 2010), yet the complete insularity of these locations prevents dispersal. To the best of our knowledge, we are witnessing the early stages of the first documented case of *Rangifer* intentionally introduced to one large island (i.e. Adak) becoming invasive at another large island (Kagalaska).

We do not know for certain how far caribou swam to reach Kagalaska, but such crossings are not risk-free. Although Kagalaska Strait is only 400 m wide at its narrowest point, crossing at this constriction is unlikely given the strong rip tides and steep, rocky shoreline. Actual swim distances may be substantially greater when taking currents and accessible entry-exit points into account. If caribou select protected coves with accessible and gradually sloping beaches as entry points and the tide is not slack, swim distances could easily range 2.0–3.0 km. These distances are comparable to those for Peary caribou (*R.t. pearyi*) swimming across open water in the Canadian high arctic (Miller 1995). However, home ranges for these

animals span multiple islands that are connected by traversable sea ice in winter (Miller et al. 2005). Reindeer introduced to Stuart Island in the Norton Sound of Alaska also swam across at least 2 km of open water to the mainland, yet these water routes were also previously traversed over sea ice in the winter (Swanson and Barker 1992). Successful open water crossings as well as knowledge of resource distribution at different islands may be enhanced through gaining a familiarity of the overall landscape during previous movements over sea ice. Olfactory cues on sea ice (i.e., inter-digital gland secretions, feces, urine) may also determine and reinforce movement paths to a greater extent than visual cues on the horizon (Miller et al. 2005). In contrast, caribou that initially swim across year-round ice-free waters presumably lack a priori knowledge of available resources on the opposing side, nor would they have olfactory cues to guide them across a safe and efficient route. Swimming caribou also may be naive to obstacles on the opposite shore so they cannot be certain if 'pre-targeted' exit points are free from significant hazards such as rocky intertidal zones or kelp beds. Caribou have been observed struggling after becoming entangled in kelp while swimming to small islets in protected bays on the west side of Adak (W. Pepper and D. Erickson, USFWS *M/V* Tiglax, pers. commun.). Strong currents may also push swimming caribou beyond their intended accessible exit point and, in a worst case scenario, out to sea. For example, USFWS field crews encountered a reindeer skeleton on Kasatochi Island in the central Aleutians in 1996. Notably, the closest population of nonindigenous reindeer occurs on Atka Island, which is separated from Kasatochi by a 20 km wide oceanic pass with strong currents and tides. Furthermore, Unimak Island (the only island in the archipelago with native caribou) is only separated from mainland Alaska by 0.5 km wide Isanotski Strait, yet emigration from the mainland does not appear to be a consistent metapopulation dynamic component (Valkenburg et al. 2001). Isanotski Strait has strong tidal currents much like Kagalaska Strait. We can only speculate as to the frequency of successful inter-island crossings between Adak and Kagalaska, but such movements are certainly not without risk.

This leads to the question: what ecological conditions serve as a catalyst for caribou to swim across unfamiliar waters to Kagalaska, and how could a new population become established? First, male caribou may ephemerally utilize Kagalaska as part of strategy to meet life history demands. Some hypothesized mechanisms for sexual segregation among ungulates postulate that males reduce intersexual competition during the non-breeding season in order to maximize forage intake that can lead to larger body size and increased mating success, yet this can also involve riskier behavior (Main et al. 1996). Assuming female caribou are not encountered on Kagalaska, males would swim to Kagalaska to take advantage of abundant resources, and then swim back to Adak before the rut in early fall. Females may be reluctant to risk crossing the strait while still caring for calves that are not strong swimmers. Second, the colonization of Kagalaska may be associated with the disparity in seasonally important forage types between islands. Fruiticose lichens (e.g., *Cladina rangiferina*, *C. stellaris)* that are preferred by *Rangifer* in winter have been depleted on Adak, whereas lichen mats are still common on Kagalaska (Ricca, unpublished data). Caribou sign detected during our summer surveys likely reflects use within approximately 2 months or less (Weckerly and Ricca 2000; Ricca, unpublished data), so we cannot be certain that caribou inhabit Kagalaska during winter when foraging on lichens would be greatest. However it is important to note that the benefit of available lichens would be relatively short-term due to their extremely slow growth rates. Overgrazed stands can take >40 years to fully recover (Klein and Shulski 2009) and lichen depletion is associated with population crashes among *Rangifer* introduced to islands with more severe arctic climates, yet insular populations in more temperate latitudes (such as the Aleutians) may persist by foraging on rank graminoids during winter even after lichens are decimated (Leader-Williams 1988; Klein 1991). Third, year-round food limitation for Adak caribou may have intensified following the recent increase in caribou population size; hence, the rate of dispersal to Kagalaska where forage is abundant may be density dependent. The probability of successful establishment by a nonindigenous species is often positively correlated with the number of dispersing individuals, particularly if dispersal is risky (Kolar and Lodge 2001). Moreover, colonizing populations of introduced reindeer in Alaska often numbered <30 (Swanson and Barker 1992), and only 7 animals (3 males, 4 females) founded the South Georgia Island herd in the

South Atlantic (Leader-Williams 1988). Thus, relatively few reproducing females could form the basis of an established population on Kagalaska.

Although we show strong evidence that caribou currently inhabit Kagalaska to some unknown extent, their effect on plant community structure appears minimal to date. In addition to the presence of intact lichen stands, *Empetrum nigrum* mats are not compacted as would be expected by extensive trampling by caribou. Moreover, caribou trails and associated soil erosion common to high density areas on Adak are not apparent on Kagalaska (Ricca, unpublished data). Reported low rates of immigration to Unimak from the Alaska Peninsula (Valkenburg et al. 2001) could be extrapolated to Adak—Kagalaska movements as a rationale for low probability of population establishment, yet caribou population dynamics on Unimak are influenced by predators (e.g., brown bears (*Ursus arctos*), wolves (*Canis lupus*)) that are nonexistent on all other islands in the archipelago (USFWS 2010). A reproductively viable Kagalaska caribou herd could over-exploit resources at a rapid rate given that the island is approximately 6-times smaller than Adak, and management efforts would be hampered by the rugged and remote nature of the island. Moreover, the mixed private and federal land ownership on Adak complicates source population control options. Successful colonization of islands to the west of Adak is unlikely given that caribou would have to swim 15 km across Adak Strait to Kanaga (Fig. 1). However, a worst case scenario would involve a stepwise and eastwardly dispersing metapopulation, beginning with the invasion of Little Tanaga from Kagalaska across Little Tanaga Strait (minimum distance = 2.5 km), followed by Umak Island across Umak Pass (1.2 km), Kanu Island across Asuksak Pass (2.6 km), and finally Great Sitkin Island across Great Sitkin Pass (2.0 km) (Fig. 1). Though such an invasion would take time and require substantial risk taking behavior by dispersing caribou, our observations suggest it is plausible.

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