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The winter energetics of the Azores bullfinch and the implications for the restoration of its native laurel forest habitat

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ABSTRACT

The Azores bullfinch *Pyrrhula murina* is an endangered endemic bird species restricted to the east of the island of São Miguel, Azores. In the past decades, the native habitat of the bird was gradually invaded by exotic plants and less than 30% of its range is currently occupied by native vegetation. The late winter has been suggested as a critical period for bird survival as a consequence of food shortage. We developed a model to understand how yearly and seasonal variations on the type and abundance of food items affect the winter energetic budget of the Azores bullfinch. The model is at steady-state as it simulates the winter-early spring period, when Azores bullfinches attain maximum weight, with non-significant fluctuations. The costs of basal metabolic rate (BMR), thermoregulation and other activities are included in the model. The potential energy available to Azores bullfinch between January and April in three different years was estimated based on day length, diet, pecking rates on different food items, their energetic content and assimilation efficiency. Simulations were run with probability distributions of the estimated available energy and the energy left for activities of the Azores bullfinch. Results indicate that between January and April, the bird's energetic requirement for BMR and thermoregulation range between 118 and 123 kJ d^{-1}, peaking in March due to thermoregulation constraints. If the bird's energy with activities represent 36% of the energy spent with BMR plus thermoregulation, the estimated daily energy requirements of the Azores bullfinch fall within 160–167 kJ d^{-1}. Results indicate that January and February are months when the bird may experience some kind of energy constraint due to low density of energy-rich items (<200 kJ feeding area^{-1}). However, from March onwards and particularly in warmer years, the Azores bullfinch will have plenty energy for BMR, thermoregulation and activities, mostly due to the increasing consumption of *Ilex perado* flower buds. In relation to altitude variations, simulations indicate that thermoregulation costs increase 8 and 13% at mid- and high-altitude, respectively, compared to low-altitude. In terms of habitat management, we can infer that removing the exotic tree *Clethra arborea* should be undertaken with caution because, during winter *C. arborea* seeds constitute an important food item to the bird. Alternatively if *C. arborea* is replaced by other energetically rich items, particularly at lower altitudes, the Azores bullfinch will potentially benefit from it.

1. Introduction

The Azores bullfinch *Pyrrhula murina* (Aves: Passeriformes; Fringillidae) is an endemic bird restricted to about 15 ha in the east of the island of São Miguel, Azores (Ceia et al., 2011b) (Fig. 1). A population size of 1608 individuals was estimated (Monticelli et al., 2010) and the species is listed as Endangered (IUCN, 2010; Ceia et al., 2011b) and regarded as a flagship species for its habitat, the native laurel forest (Ramos, 1996a; Ceia et al., 2009). In the Azores, native laurel forest remains only at high altitude in the cloud zone of a few islands, on steep slopes, ravines, cliffs and volcanic craters (Schäffer, 2002). In São Miguel, the largest island of the archipelago, the last fragment of native laurel forest comprises nearly 2.013 ha in the east area of the island (Ceia et al., 2011b). This area has been invaded by aggressive exotic plants, in particular, Australian cheesewood (*Pittosporum undulatum*), Lilly-of-the-valley-tree (*Clethra arborea*) and Kahili ginger (*Hedychium gardneranum*) (Silva, 2001). These plants are replacing the rich biodiversity of the laurel forest (Heleno et al., 2009), upon which the Azores bullfinch is largely dependent, and do not provide

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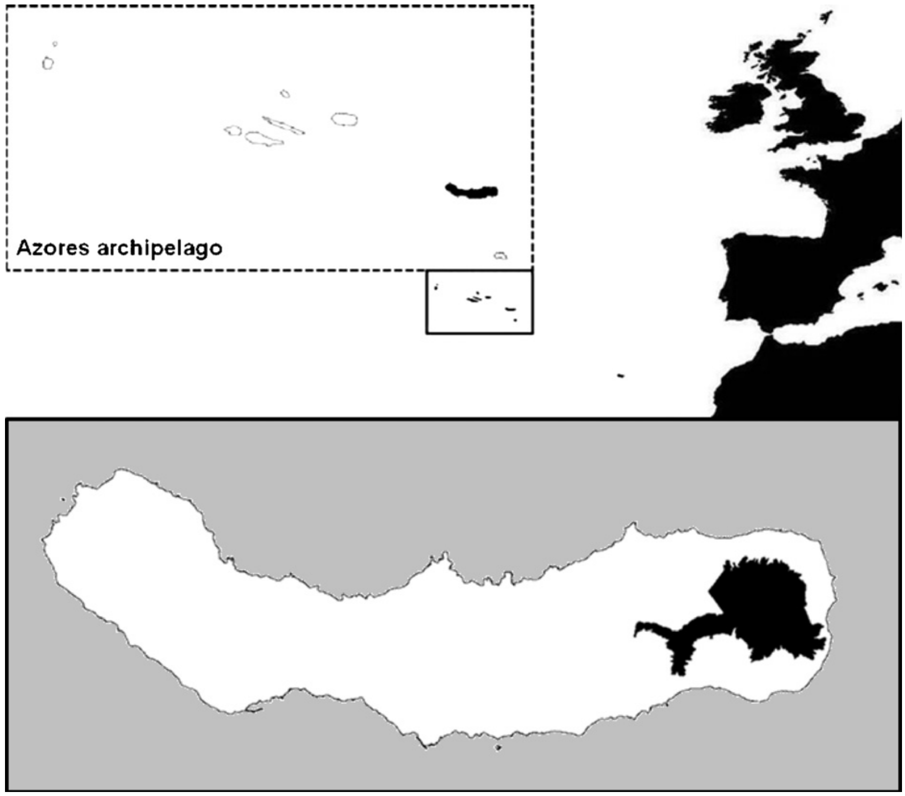

Fig. 1. Location of the study area in São Miguel Island, Azores (Portugal). The Azores bullfinch range, largely confined to the remaining patches of laurel forest in the eastern part of São Miguel, is shown below.

alternative food resources for this bird species, with the important exception of *C. arborea* (Ramos, 1995, 1996b; Ceia et al., 2011a,b). In fact, Ramos (1995) suggested that the expansion of *C. arborea* in the past decades may have benefited the Azores bullfinch but its rapid expansion is currently outcompeting native plants that are also important food sources for this species. Therefore, progressive control of invasive exotic plants (mainly *C. arborea* and *H. gardneranum*) has been recommended and areas of native vegetation are being restored through habitat restoration projects since October 2003.

However, there are uncertainties about the success rate of replacing exotic with native plants and how long it will take for the native vegetation to recover. It is likely that changes on the dominant vegetation type affect the energetic budget of the Azores bullfinch, especially during winter, an energetically critical period. Ramos (1995) showed that *C. arborea* is an important winter food source, which suggests that the Azores bullfinch must find alternative food sources in areas where *C. arborea* is cleared. It has been shown that areas cleared from *C. arborea* were at least as heavily used by Azores bullfinches in winter as non-cleared areas (Ceia et al., 2011a,b), suggesting that conservation management has not reduced habitat suitability in the short-term.

Bioenergetic models are adequate tools to explore the links between the growth of an organism and its food resources (e.g. Libralato and Solidoro, 2008; Madon et al., 2001; Martins et al., 2004) as their basic equations account for the difference between the energy assimilated in food and the energy spent via several processes throughout time. In this way, it is possible to follow variations on body mass, as an indicator of the organism growth and physiological condition.

Our goal was to develop a bioenergetic model of the Azores bullfinch to understand the impacts of seasonal and yearly variations in food items and temperature. Specifically, we aimed to predict the consequences of removing an important exotic plant (*C. arborea*) on the bird's energetics during the winter period.

2. Materials and methods

2.1. Bioenergetics model at steady-state

The Azores bullfinch breeds in July–August and juveniles perform a partial moult two months after fledging, resembling adults from October onwards. During the winter-early spring period, from January to April, they do not significantly change weight (Ramos, 1994b, 1998). The present model was developed for this period, for a bird with a constant weight of 31 g fresh weight (SD = ±2.15; N = 73), which was described through Eq. (1):

$$\frac{\partial W}{\partial t} = (AE \times \omega) - (WE \times \omega) = 0 \quad (1)$$

W is the Azores bullfinch weight (g fresh weight), AE and WE are assimilated and expended energy, respectively (kJ d^{-1}), ω is the weight conversion factor (Table 1).

AE by Azores bullfinches was described as:

$$AE = MaxAE \cdot \frac{TE}{TE + km} \quad (2)$$

$MaxAE$ is the maximum assimilation rate by Azores bullfinch (kJ d^{-1}), which is weight-specific, TE is the available energy from food items per feeding area (kJ feeding area^{-1}) and Km is the half-saturation constant for energy assimilation (kJ feeding area^{-1}).

In many cases, the maximum value of the daily energy expenditure (*DEE*) for birds is assumed to be ~4 times the basal metabolic rate (Bryant, 1997; Wiersma et al., 2005). Since the model is at steady-state, the following condition is verified:

$$MaximumDEE = MaxAE \quad (3)$$

The value of Km (Table 1) was estimated by a linear transformation of the Michaelis–Menten equation, where Km is given as the