Promotion of ecosystem carbon sequestration by invasive predators

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Despite recent interest in understanding the effects of human-induced global change on carbon (C) storage in terrestrial ecosystems, most studies have overlooked the influence of a major element of global change, namely biological invasions. We quantified ecosystem C storage, both above- and below-ground, on each of 18 islands off the coast of New Zealand. Some islands support high densities of nesting seabirds, while others have been invaded by predatory rats and host few seabirds. Our results show that, by preying upon seabirds, rats have indirectly enhanced C sequestration in live plant biomass by 104%, reduced C sequestration in non-living pools by 26%, and increased total ecosystem C storage by 37%. Given the current worldwide distribution of rats and other invasive predators, seabird colonies, these predators may be important determinants of ecosystem C sequestration.

Keywords: carbon; island ecology; rats; seabirds

1. INTRODUCTION

There has been considerable interest in determining the effects of global change on the storage of carbon (C) in terrestrial ecosystems (Schimel et al. 2001). Much of the effort directed to understanding these effects has focused on global climate change, CO2 enrichment and nitrogen deposition (Körner 2000; De Vries et al. 2006). Although human-induced alterations of biological communities through invasions by exotic species are also major components of global change (Vitousek et al. 1997), we know little about the effects of biological invasions on ecosystem C storage. The handful of recent studies that have recognized this issue provide some evidence of alterations of ecosystem C stocks by locally abundant invasive plants (Jackson et al. 2002; Bradley et al. 2006; Litton et al. 2006), earthworms (Frelich et al. 2006) and deer (Wardle et al. 2001). However, most of these studies have focused only on above- or below-ground C storage, rather than on whole-ecosystem storage, or on how storage is partitioned between above- and below-ground compartments.

Rat species (e.g., Rattus rattus, Rattus norvegicus and Rattus exulans) have been accidentally introduced by humans to many regions worldwide and are among the most widely distributed of all invasive mammals. In coastal and island communities, they frequently serve as top predators by consuming seabird eggs and chicks, thereby severely reducing their populations (Cournach et al. 2003). In the absence of introduced predators, seabirds function as major ecosystem drivers in many coastal communities worldwide, in part because they transport labile forms of C and nutrients from the ocean to the land (Polis & Hurd 1996; Mulder & Keall 2001). Introduction of predators of seabirds to these communities therefore interrupts this sea-to-land transfer of resources (Croll et al. 2005; Fukami et al. 2006).

In this study, we considered a group of 18 forested islands off the coast of northern New Zealand, to determine how invasion by rats affects ecosystem C sequestration. These include nine islands that have never had rats and that support high densities of seabirds nesting in burrows, and nine that have been invaded by rats and have severely reduced densities of seabirds. We used this system to investigate whether and how invasion by predatory rats influenced ecosystem C storage both above- and below-ground, as well as overall ecosystem C sequestration.

2. MATERIAL AND METHODS

For each of two plots on each of the 18 islands, we measured total ecosystem C storage both above- and below-ground. This included total C storage in live plant biomass and in each of three non-living pools. These non-living pools were coarse woody debris (CWD), surface litter (dead twigs and leaves) and soil at each of three depths (0–10, 10–20 and 20–30 cm). Individual islands served as the units of replication and all response variables were analysed by analysis of variance (ANOVA) or analysis of covariance (ANCOVA) to test for significance of differences between rat-invaded and rat-free islands.

Methodology is outlined in detail in the electronic supplementary material, appendix §A.

3. RESULTS

We found large differences between rat-free and rat-invaded islands in the total amounts of C stored (table 1; figure 1). The amount of C stored in live plant biomass on plots on rat-invaded islands was on an average 204% that on plots with dense seabird burrows on rat-free islands (figure 1). Conversely, the amount of C stored in non-living pools on rat-free islands was 138% that on rat-free islands. This is because rat-free islands had greater amounts of C stored in the soil than rat-invaded islands, particularly at lower soil depths (table 1; figure 1). Rat invasion did not have a significant effect on C storage in above-ground non-living pools such as CWD and plant litter; these pools collectively represented less than 3% of C stocks. Our results show that rat invasion caused a large increase in the proportion of ecosystem C stored in live plant biomass (figure 1). Since the positive effects of rats on C storage in live plants exceed their negative effects on C storage in non-living pools, invasion by rats promotes total ecosystem C sequestration on average by 36.7%.

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4. DISCUSSION

Few studies have considered effects of invasive organisms on ecosystem C sequestration either above- 
ground (e.g. Bradley et al. 2006; Litton et al. 2006) or 
below-ground (e.g. Wardle et al. 2001; Frelich et al. 
2006). Further, the issue of how invasive species 

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The effects of non-native organisms on ecosystem C sequestration have been largely overlooked, especially when compared with other drivers of human-induced global change. Our results in total point to large effects of a widely distributed invasive predator on ecosystem C storage and on the partitioning of C storage between above- and below-ground pools. As such, they highlight the need to explicitly consider the ecosystem-level consequences of invasive biota in order to better understand how the global C cycle responds to global environmental change.

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(but see Jackson et al. 2002). Our study provides clear evidence that invasion by introduced rats has significant effects on both above- and below-ground C storage, but that these effects work in different directions.

Seabirds have two main effects on C storage which are impaired when they are subjected to predation by rats. First, seabird damage to tree roots through burrowing during nesting undermines tree stability (Maesako 1999), and this may reduce tree biomass and C storage in live tissue, which is consistent with our data. These effects override any positive effects that seabirds might exert on plant growth through fertilization due to transport of nutrients from the ocean to the land (Fukami et al. 2006). Second, seabirds transfer significant quantities of resources containing C from the ocean to the land (Polis & Hurd 1996; Croll et al. 2005; Fukami et al. 2006), which increases the amount of C stored in the soil. In this light, earlier work has shown that seabirds on offshore islands in central New Zealand can add 4–50 g m⁻² of guano to the ground surface each week (Mulder & Keall 2001).

These effects are all reversed by predation of seabirds by rats. Rats are omnivores that consume vegetative biomass and reduce tree seedling establishment (Atkinson 1985), but these negative effects are apparently overridden by their positive effects on seedling density and plant biomass through reducing seabird burrowing activity (Fukami et al. 2006). Thus, rat invasion causes the ecosystem to shift from a state where just over half the total C is stored in non-living pools to one in which most of the C is stored in live plants. Since the positive effects of rats on live plant C storage outweigh their negative effects on C storage in non-living pools, invasion by rats promotes the total amount of C sequestered in the ecosystem.

Our study focused on offshore islands and is most relevant to coastal forests. However, these types of effects are likely to be important in many other coastal systems, given the widespread influence of invasive predatory mammals on seabird populations throughout the world (Couchamp et al. 2003; Blackburn et al. 2004). In New Zealand, the disappearance of extensive nesting seabird communities over the past several centuries following the introduction of predators (notably rats; Worthy & Holdaway 2002) has probably exerted large effects on C storage in many coastal forests. Some of these effects probably occur further inland given that, in the absence of predators, several seabird species nest 50 or more kilometres inland from the coast (Worthy & Holdaway 2002). While our results are most relevant in the order of 50–150 years following predator invasion, the nature of these effects in the long-term perspective (i.e. multiple tree generations) is less clear. Factors that may determine these longer-term effects are the long-term nature of population dynamics of rats and seabirds and the rate at which C turns over in both the above- and below-ground pools.


