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Responses by farmers to the apple snail invasion of Ecuador's rice fields and attitudes toward predatory snail kites

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ABSTRACT

Since its introduction in the mid-2000s, the apple snail, *Pomacea canaliculata* (Lamarck) has spread throughout Ecuador's southern lowlands. This paper collates information from government surveys, farmer interviews and roadside mapping to track the distribution and rate of spread of the snail. The paper also examines the impact on the rice (*Oryza sativa* L.) sector of the snail invasion and farmers' preferred management practices in response to high snail densities. Since its initial introduction, and following severe flooding in Guayas and Los Rios Provinces during 2008, the snail has invaded most of Ecuador's major rice-growing regions. The snail invasion of Ecuador has been fundamentally different from other regional invasions because of the presence of a specialized snail predator, the snail kite, *Rostrhamus sociabilis* Vieillot. Snail kite densities increased in response to the snail invasion, but snail densities have remained high, particularly in areas of 'stepped rice' – where rice is planted to floodplains in response to natural receding of water levels. The Ecuadorean government responded to the snail invasion by investing in data collection, farmer training and molluscicide distribution. Farmers have overwhelmingly opted to control the snails using insecticides and molluscicides despite training in alternative control methods; however, farmers have experienced increased rice damage from insects and diseases that may be associated with high pesticide use. Farmers perceive snail kites as beneficial predators, but have not been pro-active in enhancing kite numbers or their efficiency. We present a series of recommendations for sustainable apple snail management in Ecuador.

1. Introduction

The golden apple snail, *Pomacea canaliculata* (Lamarck), is considered among 100 of the World's worst invasive species (Global Invasive Species Database, 2013). This aquatic snail is originally from South America (Argentina) but has spread (by accident and through deliberate introduction) to several regions outside its native range. The species is now established in South America – west of the Andes (Chile and Ecuador), in North America (USA), East and South East Asia, and most recently in South Asia (Pakistan) (Hayes et al., 2012; Horgan et al., 2014). A similar species, *Pomacea maculata* Perry, also from South America (Brazil) has also invaded several parts of East and South East Asia (Indonesia, Taiwan, Thailand), and has recently been introduced to Spain (Hayes et al., 2012; Horgan et al., 2014). Both *P. canaliculata* and *P. maculata* have been associated with high levels of damage to rice (*Oryza sativa* L.), particularly in South East Asia (Joshi and Sebastian, 2006) although under certain conditions *Pomacea* spp. are also pests of rice in their native range (Cowie, 2002; SOSBAI, 2010). Invasions by apple snails to new regions in recent years (e.g., Pakistan – Baloch et al., 2012; Spain – EFSA, 2012; Western Myanmar – communication with Plant Protection Division of the Myanmar Agriculture Ministry) indicate that these species continue to spread to isolated new locations in rice growing regions, from where they can increase in range by dispersing through waterways and wetlands. Despite the importance of apple snails to the rice sector, there are few detailed reports on the dynamics of apple snail invasions in rice-growing regions or the economic, social or ecological impact of these invasions for the rice sector (but

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see Halwart, 1994; Naylor, 1996). Careful documentation of the spread of apple snails and their impact can help guide responses by both government entities and rice farmers as snails move into new regions.

Apple snails damage rice by feeding on the delicate rice seedlings soon after sowing or transplanting. At relatively moderate densities (ca. 2 adults m^{-2}), and without adequate cultural control methods, they can cause losses of between 30 and 100% of seedlings (Litsinger and Estano, 1993; Teo, 2003; Wada, 2004). The snails generally avoid older rice plants because of higher specific dry matter content (i.e., tougher plants) (Sanico et al., 2002; Teo, 2003; Yanes Figueroa et al., 2014). Three factors interact to determine damage levels: 1) snail density; 2) the age or size of the rice seedlings; and 3) water depth (Litsinger and Estano, 1993; Teo, 2003). Each of these factors can be related to rice-crop establishment methods, and cropping practices. For example, even in regions where apple snails are native and snail densities are low, damage to wet-direct seeded rice (also known as pre-germinated rice) can be high (e.g., *Pomacea* sp. in Brazil and *Pomacea doliodes* (Reeve) in Suriname [Cowie, 2002]) – since small snails (hatchlings and juveniles) can damage the tiny developing cotyledons of wet direct-seeded rice (Teo, 2003; Wada, 2006). In native regions, transplanted rice seedlings are apparently only rarely damaged (Cazzaniga, 2006; SOSBAI, 2010); however, in invaded regions, transplanted rice seedlings are sometimes heavily damaged or killed by snails, resulting in missing hills or patches of bare ground that require replanting (Litsinger and Estano, 1993).

P. canaliculata was discovered in Ecuador in 2005 where it causes severe damage to rice (Felix et al., 2011; MAGAP, personal communication). This invasion has been different from previous invasions to tropical rice growing regions (i.e., South East Asia) because it concerns the introduction of an apple snail to a region with a highly specialized predator of native apple snails – the snail kite, *Rostrhamus sociabilis* Vieillot (Alava et al., 2007). Snail kites are potential regulators of apple snail populations that respond spatially to high snail densities by increasing foraging activity (Beissinger, 1983; Bourne, 1985; Darby et al., 2012). Although the snail kite has never been introduced for biological control purposes, it is tempting to suggest that the kite plays a significant role in maintaining snails at low densities in native regions. Monitoring of events related to the introduction of *P. canaliculata* and its spread through Ecuador could help determine the role of snail kites in regulating populations of *Pomacea* spp., and should add considerably to understanding the dynamics of these invasive snails in general.

The present study describes the first 9 years after the initial discovery of *P. canaliculata* in Ecuador. Using geo-referenced government records and a series of farmer questionnaires, this paper maps the distribution and spread of the snail in recent years, its impact on the rice sector, the response by government entities, and farmer adoption of management advice in snail-invaded regions. Based on an understanding of previous reports (i.e., Argentina and Brazil – Cazzaniga, 2006; SOSBAI, 2010), it might be suggested that damage to direct-seeded rice would be higher than damage to transplanted rice, especially during the wet-season and in areas where water levels are difficult to manage. In effect, if snail kites are principal regulators of apple snails, then apple snail dynamics in Ecuador might approach or emulate conditions in Brazilian rice fields where apple snails and snail kites co-occur. We examine trends in the apple snail invasion of Ecuador and area-wide responses by snail kites. Based on our results, we discuss possibilities for establishing integrated approaches to snail management that include conservation of significant snail predators such as the snail kite.

2. Materials and methods

2.1. Farmer surveys and field mapping

Data on the distribution of snails were collected by personnel of the Agencia Ecuatoriana de Aseguramiento de la Calidad del Agro (Agrocalidad – Guayas and Los Rios Provinces) during regular field visits to rice farms between 2010 and 2013. During these visits, farmers were briefly interviewed, rice fields inspected for snails and other damage, and samples of snails collected for later identification (Felix et al., 2011). Each visit was carefully documented and geographical coordinates were recorded together with the collected samples. Personnel of Agrocalidad interviewed farmers using a structured questionnaire during visits to arbitrarily selected rice fields in 2013, noting the geographical coordinates of farmer fields (using GPS), the presence/absence of snails, the levels of damage (or replanted areas) and the control methods that farmers used. During July 2013, the questionnaire was modified by adding a series of questions related to snail kites. A total of 164 farmers completed the questionnaires, of these 73 were interviewed regarding snail kites.

During June–July 2013, a mapping study was conducted to corroborate the results of farmer interviews. Using GPS, 158 waypoints were recorded during 6 roadside transects through Guayas (Daule-Salitre, Samborondon, Milagro, Naranjito), Los Rios (Babahoyo) and Manabí (Portoviejo) Provinces. All categories of road were used, particularly agricultural roads through rice landscapes. A further 8 waypoints were recorded in non-rice habitat in Manabí Province along the Chone River and Estuary between Bahía de Caráquez and Chone to the south and Chone and San Vicente to the north. Waypoints were recorded after every 3 km traveled (according to the vehicle odometer), recording rice crop stages, crop establishment methods, damage to seedlings (estimated visually), number of snail kites visible, snail kite perching structures (wires, posts, trees, etc., on which the kites were observed), the estimated area of rice crops at different cropping stages (land-preparation, crop-establishment, early vegetative stage, late vegetative stage, flowering, grain-filling, ripe for harvest, and harvested [stubble]), areas of other crops (e.g., corn [*Zea mays* L.], soya [*Glycine max* (L.)], sugarcane [*Saccharum* sp.]) and other habitat types (e.g., wetland, forest, tree groves, urban). Area estimates and bird counts were from 20 ha fringes at either side of the road at each waypoint. Where views were blocked (at forests and fruit groves) the areas were verified on Google Maps. Damage estimates were from rice fields ($\leq$1 ha) immediately adjacent or close to the roadside. At 20 waypoints with recently-prepared (flooded), transplanted rice fields, snail densities were also recorded by counting egg masses in 10 $\times$ 1 m quadrants along the edge of each of 3–5 rice fields.

2.2. Data analyses

The perceived importance of pests, diseases and other crop problems for farmers practicing direct seeding or transplanting during wet and dry seasons was assessed using three-dimensional contingency tables with crop problem, crop-establishment method and season as dimensions. A similar analysis was used to determine water sources for farmers during the two seasons and using different crop establishment methods (dimensions = water source, crop-establishment method and season). Tests for mutual independence, partial independence of each of the three dimensions, and comparative frequencies were conducted using the appropriate chi-squared analyses according to Zar (1987). All dimensions were independent ($63.91 \leq \chi^2 \leq 912.97$, $P < 0.001$). Differences between areas planted, areas and proportions of rice crops damaged by snails and areas replanted were analyzed using univariate General Linear Models (GLM) with crop-establishment