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Short communication

# Effects of natural flooding and manual trapping on the facilitation of invasive crayfish-native amphibian coexistence in a semi-arid perennial stream

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ABSTRACT

Aquatic amphibians are known to be vulnerable to a myriad of invasive predators. Invasive crayfish are thought to have eliminated native populations of amphibians in some streams in the semi-arid Santa Monica Mountains of southern California. Despite their toxic skin secretions that defend them from native predators, newts are vulnerable to crayfish attacks, and crayfish have been observed attacking adult newts, and eating newt egg masses and larvae. For 15 years, we have observed invasive crayfish and native California newts coexisting in one stream in the Santa Monica Mountains. During that period, we monitored the densities of both crayfish and newt egg mass densities and compared these to annual rainfall totals. After three seasons of below average rainfall, we reduced crayfish numbers by manual trapping. Our long-term data indicated that crayfish did not fare well in years when rainfall is above the historic average. This invasive predator did not evolve with high velocity streams, and observations indicated that southern California storm events washed crayfish downstream, killing many of them. Newts exhibit increased reproduction in years when crayfish numbers were reduced. A comparison with a nearby stream that does not contain crayfish indicated that newt reproduction positively responded to increased rainfall, but that fluctuations were much greater in the stream that contains crayfish. We suggest that rainfall patterns help explain invasive crayfish/newt coexistence and that management for future coexistence may benefit from manual trapping.



## 1. Introduction

Invasive species are of wide concern to ecologists and conservation biologists. Impacts of invasive species are widespread and are commonly thought to be a major contributor to observed declines in biodiversity. Invasive species are known to negatively impact native species through predation, competition, or even hybridization. Freshwater systems are thought to be particularly susceptible to species declines and extinctions, and as suggested by Ricciardi and Rasmussen (1998, 1999), understanding the negative impacts of invasive species is key to managing freshwater biodiversity.

Global amphibian declines have been well documented, and invasive species have been implicated as frequent contributors to these declines (reviewed in Kats and Ferrer, 2003). In most instances the invasions are recent enough that negative impacts of the invading species can be measured by observing population reductions of native amphibians (e.g., Tyler et al., 1998). In other instances, the invasive species has persisted long enough to eliminate local native amphibian populations (Gamradt and Kats, 1996). There are few long-term examples where native amphibians and invasive predators/competitors have been shown to coexist, and in

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most instances where these interactions have been studied, scientists predict that the invasive will eliminate the native amphibian species (D'Amore et al., 2010).

In southern California, native amphibians have also been declining. Studies have suggested that invasive fish and crayfish have contributed to these declines in native amphibians (Gamradt and Kats, 1996; Miller et al., 2012; Riley et al., 2005). The only stream-breeding salamander in southern California is the California newt, *Taricha torosa*. The California newt is a long-lived terrestrial salamander that returns to streams each winter/spring to breed. The skin of adult newts contains a neurotoxin that protects it from most terrestrial and aquatic predators. After breeding, female newts remain in the streams to deposit small (2–3 cm diameter, 15–30 embryos each) egg masses by attaching them to rocks or vegetation. Egg masses contain the neurotoxin and are not preyed on by native aquatic predators.

The swamp crayfish is native to the southeastern United States but is now widespread around the world (Gherardi, 2011). In some instances it has been introduced as a source of food for humans, but in southern California its introduction to local waterways is related to its widespread use as fishing bait. Despite toxins in the skin of adult newts and the egg masses that provide defense from most native predators, these invasive crayfish are known to attack and either destroy or damage adult newts, larvae and egg masses (Gamradt and Kats, 1996; Gamradt et al., 1997). For instance, over a 24 h period no newt larvae survived crayfish predation in enclosure experiments, and previous field surveys clearly indicate that introduction of crayfish to local streams is correlated with either decline or local extinction of newt populations (Gamradt and Kats, 1996).

Most streams of the Santa Monica Mountains National Recreation Area in southern California that historically contained populations of the California newt experienced local extinction of this amphibian upon introduction of the swamp crayfish (Gamradt and Kats, 1996; Riley et al., 2005). These streams contained newts when surveyed in the 1970's but did not contain newts when surveyed again in the 1990's. In contrast, streams with no history of invasive predators, including crayfish, still contained newts. Therefore, extinction of local newt populations appears attributable to invasive predators, such as the crayfish.

Unlike most streams in the Santa Monica Mountains, where native newts have been extirpated by crayfish and other invasive species, one stream, Trancas Creek, contains both invasive crayfish and California newts that appear to persist in sympatry much longer than other streams surveyed since the 1990's. Trancas represents one of several creeks that have been monitored annually since 1996. Near the headwaters of this stream are man made ponds that have been stocked with non-native fish in the last 50 years. These ponds also contain the red swamp crayfish that likely accompanied the stocking of non-native fish. In comparison to several other creeks in the area, Trancas is predicted to have peak discharges that rank fourth relative to the 13 creeks assessed as part of the steelhead trout assessment (Harrison et al., 2005). Kerby et al. (2005) suggested that stream flow in the Santa Monica Mountains may limit the spread of invasive crayfish. They suggested that red swamp crayfish did not evolve with high stream flow, and they found that crayfish were swept downstream during seasonal high flows produced by rainfall events. In the Santa Monica Mountain system, most rainfall and runoff occurs between January and March (Loáiciga et al., 2001). Trancas has a gradient of 80 m/km (as calculated from lowest point of surveyed reach to upstream 4 km) compared to a nearby stream that contains crayfish (Malibu Creek) with a gradient of 17 m/km. Malibu Creek once had California newts but does not contain them now (Gamradt and Kats, 1996). High discharge combined with high gradient likely make Trancas unique in the Santa Monica Mountains. After monitoring streams in the mountain range for over 15 years, we suspected that seasonal flow events associated with seasonal rainfall patterns and runoff might be facilitating newt-crayfish coexistence in Trancas Creek, and if so, patterns of newt reproduction and

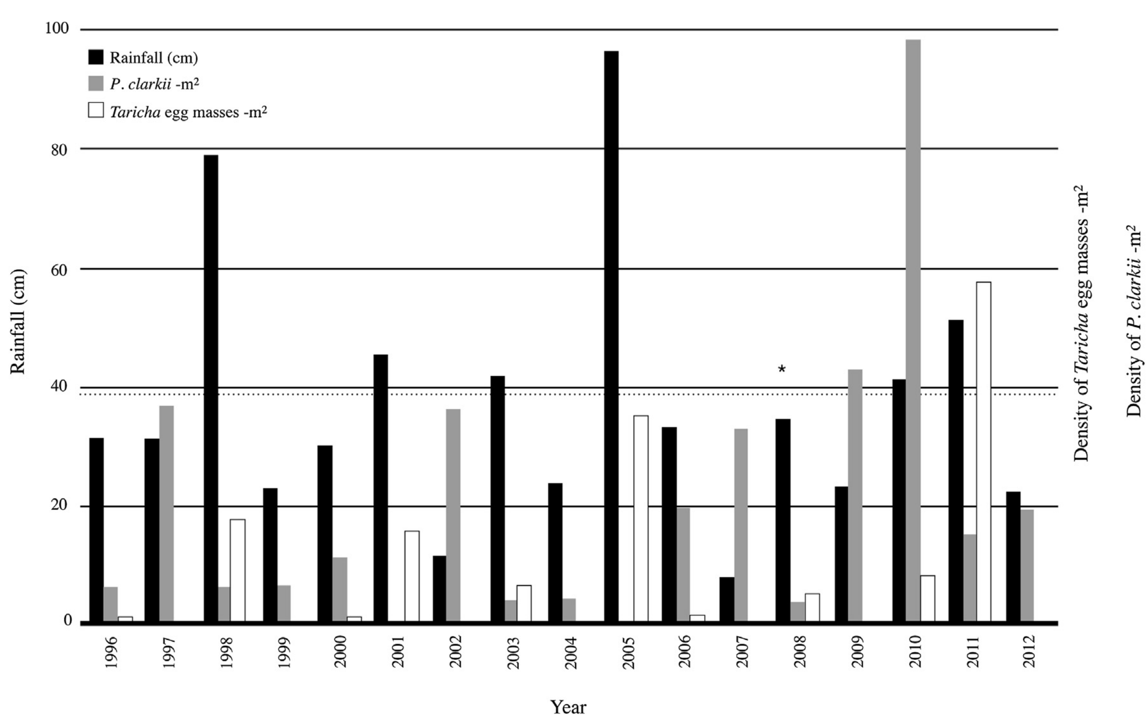


**Fig. 1.** Annual rainfall totals for Los Angeles along with densities of invasive crayfish and California newt egg masses at Trancas Creek. Dotted horizontal line indicates the historic average annual rainfall for Los Angeles. The asterisk indicates the year that crayfish were removed by manual trapping.

crayfish infestation in response to patterns of stream flow might provide information that could guide current efforts to control populations of crayfish. More recently, experiments with crayfish removal have been implemented in an effort to determine ways to mitigate potential impacts of this introduced species to the remaining newt population.

Each spring since 1996, near the conclusion of the *Taricha* breeding season, we surveyed 400 m of Trancas Creek. Each stream habitat was identified as a run, riffle or pool, and the width, length and depth of each habitat was measured. We also counted each newt egg mass and each crayfish. Egg masses are counted by feeling under rocks, stream bank edges, submerged logs and plant roots. Crayfish were counted visually. Crayfish and newt egg masses are rarely encountered in riffles, so we estimated annual crayfish and egg mass densities by only considering the surface area of pools and runs.

The southern California rainy season begins in November and runs until April. Annual precipitation is calculated from 1 July-30 June. The longest running precipitation data for the Los Angeles area are those collected at the Los Angeles Civic Center where records go back to 1877. The Civic Center is approximately 56 km from the Trancas study site. Since 1877 the average annual precipitation at the Civic Center weather station is 38.0 cm and ranges from a low of 8.2 cm (2006–2007) to a high of 96.4 cm (2004–2005).

We plotted annual newt egg mass densities and crayfish densities against annual precipitation for Trancas Creek across 17 years (Fig. 1). Historically, the heaviest rainfall occurs in January and February (climatestations.com, Los Angeles Civic Center). Newt breeding begins in March and April. In general, when seasonal rainfall totals are low (<38.0 cm), crayfish are present (11 out of 11 low rainfall years) and newt eggs mass densities are low. When seasonal rainfall totals are above average (>38.0 cm), the pattern is reversed and crayfish are often absent or undetectable (3 out of 6 high rainfall years), and newt egg mass densities are higher. In low rainfall years ($N = 11$), mean newt egg mass densities (0.012 ± 0.008 SE egg masses/m$^2$) were significantly lower than in high rainfall years ($N = 6$, 0.35 ± 0.12 SE; $U = 66$, $p < 0.01$). When compared to low rainfall years, on average egg mass densities increased 30 times in high rainfall years.

To further indicate that these dramatic changes in newt productivity in Trancas are related to crayfish population fluctuations and not just to rainfall, we are able to compare fluctuations in newt egg mass density over a six-year time frame (within the same window of years that we observed Trancas 2000–2005) to a nearby stream (19 km from Trancas) that has never had crayfish (Fig. 2). Cold Creek also has a breeding population of California newts, and we recorded densities of egg masses using the same field survey techniques as used in Trancas. Fluctuations in rainfall alone appear to influence newt productivity. In the three years where rainfall was below average, newt productivity was 0.29 + 0.09 SE egg masses/m$^2$. This level was lower than in the three years when rainfall was above average (0.76 ± 0.07 SE egg masses/m$^2$). In Trancas over the same six year time period, we recorded no newt productivity in the three (2000, 2002, 2004) below average rainfall years. The presence or absence of crayfish, as influenced by rainfall, produces the more dramatic fluctuations in the newt population at Trancas Creek; however, this is not seen at Cold Creek.

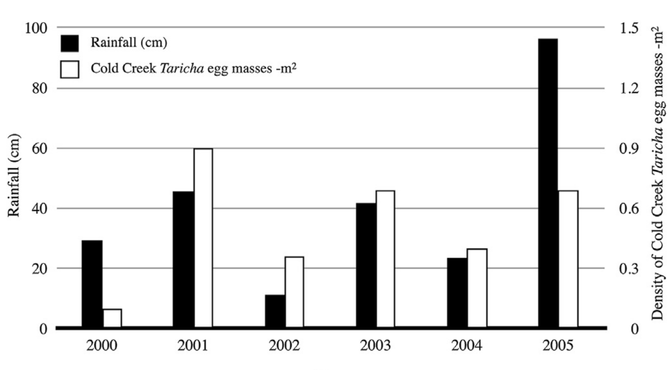


**Fig. 2.** Annual rainfall totals along with densities of California newt egg masses in a stream (Cold Creek) that does not contain invasive predatory crayfish.

In 2008, after three consecutive years of below average rainfall, we trapped and removed crayfish. Since 1996, this was the first three-year cycle where rainfall fell below average each year. We recorded no newt egg masses in 2007, and we investigated if an intensive crayfish trapping effort would allow for newt reproduction. Recent lake studies have found that intensive trapping efforts can reduce, but not entirely extirpate, invasive crayfish populations (Hein et al., 2007). Before and during the beginning of the newt breeding season in 2008, we placed 30 collapsible minnow traps throughout the 400 m section of stream that we monitor. Traps were baited with dog biscuits and were checked and emptied 5 times each week. Trapping lasted for 4 weeks. During those four weeks, we removed 6570 crayfish. After we concluded trapping, we conducted our normal survey for crayfish and newt egg masses. That year we found 0.06 crayfish/m$^2$, the second lowest density recorded for crayfish in a year with below average rainfall (11 total years with below average rainfall). We also recorded newt egg masses 0.08 masses/m$^2$. This is the highest density of newt egg masses recorded in a below average rainfall year since 1996. In 2009 there was again below average rainfall and we did not trap crayfish. This resulted in no recorded newt reproduction. Our trapping efforts suggest that intensive crayfish trapping during low rainfall or drought years can facilitate the reproduction of native amphibians. Furthermore, amphibian reproduction would not likely occur without the trapping efforts.

Crayfish are likely negatively impacted by heavy rainfall because they are not well adapted to the stream hydrology of southern California streams. Red swamp crayfish are native to the southern United States, and their native habitat includes swamps, marshes and slow moving streams and rivers (Gherardi, 2011). Kerby et al. (2005) reported that seasonal high flow velocities of streams in the Santa Monica Mountains resulted in crayfish being passively swept downstream. On numerous occasions during visits of Trancas after a spring rainstorm, we encountered dead crayfish far downstream from the normal pools and runs they inhabit. A similar recent study has suggested that tropical cyclones in Baja Mexico may be aiding in suppressing invasive bullfrog (*Lithobates catesbeianus*) populations and thus prevent the elimination of the native Baja California tree frog (Luja and Rodríguez-Estrella, 2010). Bullfrogs are also not well adapted to high velocity streams and are washed downstream during tropical cyclones.

In 2010, there was above average rainfall, yet a very high crayfish population in Trancas. Further analysis of the monthly rainfall totals indicate that in that particular year, the majority of the rainfall came early in the rainy season and very little late in the rainy season. The average rainfall totals for February and March for the other five years with above average rainfall was 29.0 cm. In 2010, the total rainfall for February and March was 12.1 cm. The low total rainfall late in the rainy season in 2010 combined with already high population numbers in 2009 provided conditions that allowed the crayfish population to reach a high density by May when surveys were conducted.

The coexistence between crayfish and native California newts observed at Trancas is not the pattern seen at other local streams colonized by crayfish (Gamradt and Kats, 1996). Unlike Trancas, amphibians in these streams were eliminated subsequent to crayfish invasion. The differences observed between Trancas and these streams are likely related to hydrologic variability between watersheds (see for example, Singh, 1997). Light (2003) noted that invasive signal crayfish (*Pacifastacus leniusculus*) were most abundant in low gradient streams and less abundant in high gradient streams in drainages of the eastern Sierra Nevada, California. Cruz and Rebelo (2007) also noted that *Procambarus clarkii* was a widespread invader in southwest Iberian Peninsula streams, but appeared unable to colonize streams with high flow. The same is likely true in the Santa Monica Mountains. Where stream gradients are low, crayfish populations are likely to be persistently high, with native amphibians being eliminated. This study suggests that there are unique instances, influenced by habitat and climate, where the end result of an invading predator may not include elimination of native amphibians. Our field observations also indicate that two species of stream-breeding tree frogs (*Pseudacris regilla* and *Pseudacris cadaverina*) persist in Trancas despite invasive crayfish.

Kerby et al. (2005) suggested intensive trapping of crayfish as a key component to crayfish management strategies in the Santa Monica Mountains. Our study suggests that while periodic heavy rainfall may be a key factor for the long-term coexistence of invasive crayfish and native amphibians, intensive trapping of crayfish during drought periods may facilitate amphibian breeding. Without trapping during drought, native amphibians have virtually no opportunity to breed with high densities of crayfish present.

Some climate models predict that southern California may experience modest declines in winter precipitation in the future (Hayhoe et al., 2004). If this occurs, we might predict that invasive crayfish will proliferate and that it will be difficult for native stream animals to persist. Climate change is expected to increase rainfall variability in arid and semi-arid regions (Batisani and Yarnal, 2010). This increase in variability will impact stream flows in these areas and could change the outcomes of species persistence in regions where invasive species have already colonized.

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