National Park Service
U.S. Department of the Interior
Crater Lake National Park

CRATER LAKE NEWT

At Crater Lake National Park, a unique population of amphibians is threatened by the spread of non-native crayfish. The "Mazama newt", a putative subspecies of the more common rough-skinned newt (*Taricha granulosa*), is believed to occur only within Crater Lake, a deep ultra-unproductive lake in the caldera of an extinct volcano (Mt. Mazama). The newts at Crater Lake spend most of their life in the lake along the rocky shoreline. Mazama newts have long been considered a locally-adapted population found nowhere else in the world based on distinct physical characteristics, including dark ventral pigmentation and completely aquatic life history, and have been proposed as a distinct subspecies (*T. granulosa mazamae*; Farner and Kezer 1953). Recent analysis of rough-skinned newts collected from Crater Lake and throughout the Pacific Northwest indicates that newts within Crater Lake are genetically divergent (i.e. distinct) from newt populations in nearby locations. based on 1) genetic, 2) physical, and 3) chemical differences.

<u>Genetics:</u> Genetic samples support the hypothesis that Mazama newts are isolated and distinct from newt populations outside the Crater Lake caldera (S. Spear, *unpublished*). In fact, Crater Lake's newts are easily distinguished from newts occupying wetlands and lakes located outside of the caldera of the former Mt. Mazama and throughout the species range. Further, recent DNA works shows that there are unique DNA sequences found in newts occupying Crater Lake that have not be described elsewhere.

Examples of newt belly coloration in Crater Lake and nearby Spruce Lake

<u>Toxins</u>: The toxins produced by rough-skinned newts to avoid being eaten by predators are particularly potent, making rough skinned newts one of the most toxic animals known. Newts are the only land animal to contain tetrodotoxin (TTX), an incredibly potent neurotoxin that is also found in deadly puffer fish and the blue-ringed octopus. Some newts can produce enough toxin to kill 17 humans if eaten. However, toxin sampling of newts from Crater Lake show extremely low TTX levels (whole newt toxicity = 0.50 µg; n = 24) relative to newts sampled at high elevation sites outside the caldera (whole newt toxicity = 6.91 µg; n = 25). TTX levels in newts at low elevation sites along the Oregon coast can reach levels that exceed 2,000 µg (Hanifin et al. 2008).

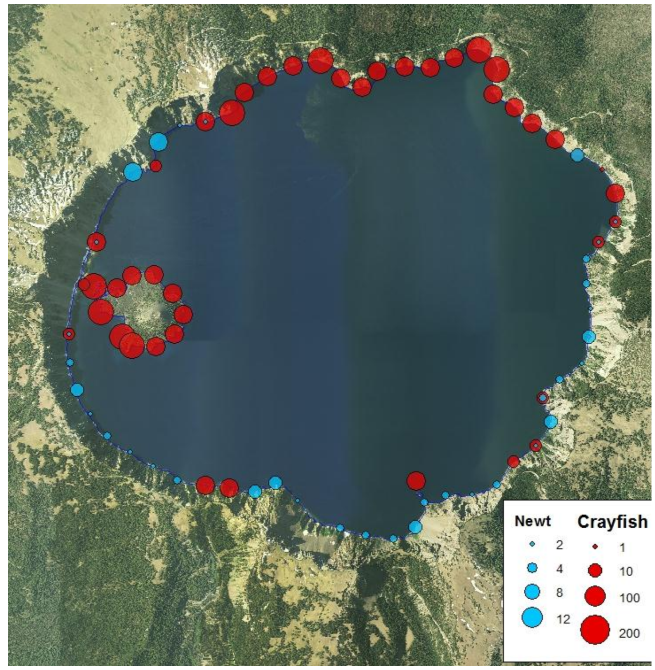
Prior to the introduction of non-native fish and crayfish near the turn of the 20th century, Mazama newts occupied the key ecological niche as the top aquatic predator. Without the need for chemical defense, the Mazama newt apparently lost the need to produce tetrodotoxin for protection. An alternative hypothesis, is that high elevation unproductive lakes simply do not provide the resources necessary for the production of TTX.

<u>Color:</u> The bright orange color on the bellies of rough-skinned newts is intended to warn predators that they are poisonous. However, in Crater Lake newts have less orange coloration and more dark pigments. The reduced bright coloration may be a response to elevated ultraviolet radiation in Crater Lake. This type of pigmentation has been observed in fish and other amphibians in areas with elevated ultraviolet radiation (UVR; Häkkinen et al., 2002; Garcia et al., 2009) and Crater Lake is more transparent to UVR penetration than any other known body of water in the world. It is also possible that reduced anti-predator strategies (TTX toxicity and bright orange coloration) were lost in an environment that lacked predators. Over time, there was less selection pressure for producing orange coloration.

This level of genetic, physical (color), and chemical (toxin levels) differentiation is particularly striking given the close proximity of breeding populations outside the Crater Lake caldera (less than 12 km). These data all indicate that newts within the Crater Lake caldera have been isolated from newt populations outside the caldera of the former Mt. Mazama such that they have adapted to the local environment.

Crayfish #VII used in mark-recapture studies

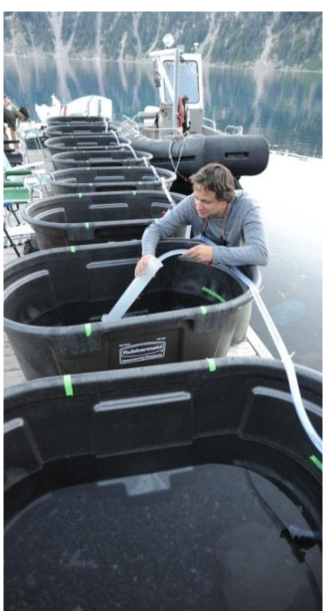
CRAYFISH



Distribution and relative density of crayfish (red) and newts (blue) in Crater Lake

Crayfish are freshwater crustaceans similar to lobsters. Crayfish introduced into new areas are known to significantly and fundamentally modify benthic plant and animal communities because of their aggressive nature and ability to devour a wide variety of food sources (omnivorous). Signal crayfish (*Pacifastacus leniusculus*) were introduced into Crater Lake around 1914 as food for previously introduced non-native trout. Crayfish now occupy approximately 1/2 of the Crater Lake shoreline, including all of Wizard Island and most of the north and northwest shore (see map). Crayfish in Crater Lake prefer nearshore habitat that includes abundant cobble and boulder size substrate (Henery et al. 2012). Although most crayfish are found in relatively shallow water, annual distribution monitoring since 2008 have repeatedly observed crayfish down to 250 m (820 ft).

It is now believed that introduced crayfish in Crater Lake have eliminated newts in almost all shoreline areas where they have become established. The results of distribution surveys conducted since 2008 show that newts were almost entirely absent from sites occupied by crayfish, yet remained locally abundant in areas where crayfish were not observed. The only instance in which newts and crayfish occupy the same location is when crayfish density is very low near the periphery of the crayfish extent. Newts appear to have been eliminated from all of Wizard Island, the north and northwest shoreline, as well as several smaller high crayfish density areas around the lake. Newts were described as common during the early to mid-20th century along the Crater Lake shoreline, Wizard Island, and Skell Channel (Farner and Kezer 1953). As recent as the mid 1980's biologists at Crater Lake National Park witnessed newts around Wizard Island; a local where they are no longer observed.



Tank experiments assessed the impact of crayfish on newt behavior.

Studies at Crater Lake by the National Park Service, U.S. Geological Survey, and University Nevada Reno have investigated the specific mechanisms by which crayfish impact newts and other benthic taxa. Controlled tank experiments were conducted at Wizard Island to assess the impact of crayfish on newt behavior and energy consumption. The tank experiments simulated the rocky shoreline conditions of the lake while controlling for crayfish presence/absence and different levels of crayfish density. The results of the experiments were strikingly clear and provide additional evidence on how crayfish impact newts. Crayfish impacts included 1) direct predation of younger newts, 2) competition for shared food sources, 3) displacement from rocky cover leading to increased fish predation, as well as 4) increased energy demands on the newts.

<u>Direct predation</u>: Crayfish clearly possess the ability to directly prey on newts. Several newts were captured and eaten during the tank experiments with no apparent adverse impact on the crayfish. Although rough-skinned newts are highly toxic to predators in other areas, the newts in Crater Lake have the lowest toxicity levels of any known population.

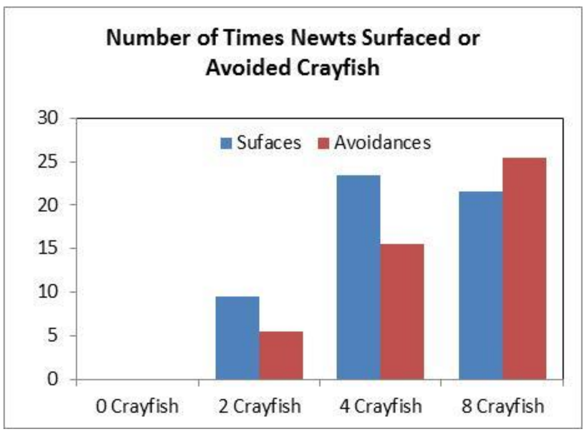
<u>Displacement from rocky habitat</u>: Like crayfish, newts usually spend daylight hours under rocky substrate. The tank experiments showed that crayfish readily displace the more docile newts out from under rocks. Newts in tanks with crayfish spent over 200% more time in the open and were exposed to direct sunlight three times more than newts in tanks

without crayfish. Displacement into the open during the day leaves newts prone to both predation from introduced trout as well as increased exposure to UVR. UVR is harmful to many species of amphibians, including rough-skinned newts. UVR is thought to decrease growth and increase activity levels of newts (Blaustein et al. 2000). UVR impacts may be especially severe in Crater Lake where high elevation combined with extremely transparent water results in extreme UVR levels during the day.

Results of tank experiments

	Newts with two crayfish compared to newts in tanks with zero crayfish
Time spent in open	**206% higher**
Time exposed to sun	**204% higher**
Time spent at surface	**162% higher**
Number of surfacing	**110% higher**

A surprising result of the tank experiments was that newts almost always swam to the water surface for a breath of air following an encounter with a crayfish. In real life outside the tanks, swimming to the surface greatly increases the risk that newts will be easily seen in the clear water of Crater Lake and eaten by rainbow trout. The experiments also showed that newts were displaced from cover more often and surfaced for air more frequently as the density of crayfish in the tanks increased.



Results of 1-hour long tank experiments showing the number of times newts avoided crayfish and traveled to the surface for air. Experiments include tanks with 1 newt and either 0, 2, 4, or 8 crayfish.

<u>Increased energy demands</u>: Newts are naturally very docile animals, hiding under cover during the day and foraging for food at night. Getting driven out from under rocks and swimming to the surface for air increases a newt's energy expenditure. In Crater Lake, food resources are greatly restricted naturally because the lake is extremely unproductive. In fact, newts in Crater Lake, even in non-crayfish areas, are significantly smaller and skinnier than newts in more productive systems outside the caldera. For example, sampling completed in 2010 showed that newts in Crater Lake had an average weight of 13.3 g (n=25) and newts in Spruce Lake, a small lake found on the west side of Crater Lake National Park, weighed 1.5 times more (average weight = 20.4 g; n=30). Combined, the reduced resources available in Crater Lake, increased avoidance measures associated with avoiding crayfish and harmful UVR, may ultimately affect the survivability of newts in crayfish dominated areas.

<u>Competition for food</u> : Newt food choice overlaps considerably with that of crayfish. Both taxa eat insects, snails, worms, and other small aquatic invertebrates found along the rocky shoreline. Crayfish are known for their voracious appetites and ability to consume an extremely wide diversity of food items, including invertebrates, vascular plants, algae, small fish, and detritus. Research at Crater Lake by the University Nevada Reno (UNR) clearly shows that crayfish have a large impact on benthic invertebrates. Both invertebrate biomass and invertebrate taxa diversity were significantly reduced in locations with crayfish compared to areas of the lake without (Henery et al. 2012). For example, the average number of aquatic worms was more than 1300% higher in non-crayfish areas compared to areas occupied by crayfish and midge (Chironomids) density was 530% higher. The total number of invertebrates was reduced on average by78% in areas with crayfish. Such dramatic reductions in food availability in an already food-limited system surely have profound negative impact on newt survival.

THE FUTURE

Based on multiple lines of evidence, we believe that the expansion of crayfish throughout the Crater Lake shoreline would lead to further declines in the abundance and distribution, and the likely extinction of the Mazama newts in Crater Lake. Unfortunately, annual crayfish distribution and abundance monitoring since 2008 at 39 evenly spaced sites around the lake, including Wizard Island (see map) suggests that crayfish are expanding. Out of 20 sites lacking crayfish from 2008-2010 (5 surveys total), crayfish were discovered at six of those sites (30%) for the first time in 2011 or 2012. Likewise, the number of crayfish caught at seven sites near the boundaries of the present crayfish invasion front all showed increasing density since 2008, several of which increasing 1-3 fold. Increasing abundance near the leading edge of the present distribution suggests crayfish expansion.

Crayfish growth and activity are temperature dependent, warmer water or a longer summer growing season could increase the rate of crayfish expansion. Spring and summer air temperatures at Crater Lake National Park have warmed such that mean summer surface water temperature has increased 2.6 °C (4.7 °F) since 1965 and the length of the summer warm water season in the lake has increased approximately 30 days.

The work described here may help identify locations within Crater Lake that could serve as sites to test future suppression efforts. Results from such actions will have far-reaching implications both in the National Park System and for aquatic resource management more generally, because introduced crayfish are a global threat to aquatic resources (Gherardi et al. 2011). Suppression strategies for non-native crayfish have been used with varying success to reduce their impact in other lakes. Suppression strategies include mechanical (e.g. trapping), physical (e.g. habitat manipulation; draining), biological (e.g. use of predators), biocidal, and autocidal (x-ray irradiation) approaches (Gherardi et al. 2011). Hein et al. (2007) demonstrated that sustained trapping (5 years) combined with fish harvest restrictions resulted in a 95% reduction in rusty crayfish (*Orconectes rusticus*). Unfortunately, trapping alone is not always successful because this approach is biased towards larger individuals. In contrast, electrofishing can be an effective means of capturing crayfish in shallow waters and this approach does not suffer from the same biases that trapping does (Gherardi et al. 2011). Recently, x-ray technologies have been used to sterilize male crayfish (Aquiloni et al. 2009). Sex pheromones have also been employed to increase catch efficiency and recent work by Aquiloni and Gherardi (2010) demonstrated that males are more likely to enter traps with females present. Crayfish suppression strategies have been initiated in Crater Lake. To date, these efforts have involved trapping of crayfish in standard minnow traps.

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