California Fish and Game 104(2): 75-85; 2018

# Using citizen science to estimate the Coastal Rainbow Trout population of Grass Valley Creek Reservoir

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Native trout and other salmonid populations worldwide are in decline due to overfishing, drought, and altered flow regimes. The successful recovery of these species requires both population monitoring and stakeholder involvement. This study engaged citizen scientists in a continuous census mark and recapture survey to estimate the population of Coastal Rainbow Trout (*Oncorhynchus mykiss irideus*) in Grass Valley Creek Reservoir. Fish were caught using hook-and-line sampling, marked via adipose fin removal, measured for fork length, and assessed for physical abnormalities. Population size was estimated as 1,924 fish (95% confidence interval: 1,443-2,780), mean fish size was 283.9 mm (SD=57.1 mm) and 95% of the sampled population had no physical abnormalities. These methods can be broadly applied to lake habitats throughout California because they are straightforward, reproducible, and easily implemented by citizen scientists who are experienced anglers.

Key words: citizen science, CPUE, Grass Valley Creek Reservoir, mark recapture, *Onchorhynchus mykiss irideus*, Rainbow Trout, Schnabel population estimate

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Anthropogenic habitat modifications and the onset of climate change have created challenging environmental conditions that have affected a wide range of organisms (Mantyka-Pringle et al. 2012). Impacts on freshwater species are of particular concern because their dispersal is limited by hydrographic constraints, and freshwater habitats have already been heavily impacted by climate change and anthropogenic stressors (Woodward et al. 2010). Though freshwater habitats cover less than 1% of our planet's surface, they support nearly 6% of known species, meaning that degradation of these habitats can have a disproportionately large effect on biodiversity (Dudgeon et al. 2006).

In California, human activities have had sizeable, negative effects on fish populations (Moyle and Williams 1990, Yoshiyama et al. 1998, Katz et al. 2013, Moyle et al. 2013). Beginning in the late 19th century, many fish populations saw marked declines in response to overfishing. The construction of dams in the 20th century fragmented much of California's riverine habitats, blocking off hundreds of miles of river and significantly changing habitat downstream of the dams. Agricultural practices have diverted water, increased siltation, introduced pesticides, and removed riparian vegetation that provides cover and temperature regulation. Logging has had similar effects, increasing siltation and reducing habitat complexity. Introduced species have preyed on native species and competed with them for resources. These activities have contributed to the status of the 25 fish taxa in California that are currently listed as endangered or threatened under the federal or state endangered species acts, including multiple species of native trout (Katz et al. 2013).

The California Fish and Game Commission established the Wild Trout Program in 1971, which was subsequently expanded in 1998 to include the Heritage Trout Program. The goals of the California Heritage and Wild Trout Program are to protect and monitor California's wild and native trout resources, conduct research and evaluate angling regulations, engage the public, and recommend new waters for designation as Wild Trout Waters (California Department of Fish and Wildlife 2017a). Currently there are 55 waters that are designated as Wild Trout Waters (California Department of Fish and Wildlife 2017b). Twelve of these waters have received the additional designation as Heritage Trout Waters, which is reserved for streams or lakes that support populations that best represent native trout populations within their historic drainage. California Senate Bill 384 (Fish and Game Code Section 1726 et seq.), passed in 2007, requires the California Heritage and Wild Trout Program to routinely inventory wild trout fisheries, and provide annual recommendations for inclusion in the program to the California Fish and Game Commission (California Department of Fish and Wildlife 2017c).

Time and resource limitations can be major obstacles to effectively monitoring wildlife populations. Given these constraints, citizen science can be an effective tool for collecting data on a species or population of particular concern (Tulloch et al. 2013). Citizen science recruits interested members of the public to contribute to scientific inquiry, including the establishment of baseline data and subsequent population monitoring (Dickinson et al. 2012). Much of citizen science focuses on observational studies, which require minimal training and equipment. A challenge in fisheries biology is that target species are often not accessible through simple observation, which necessitates specialized expertise and equipment. In fisheries research, early studies that used citizen science focused on observational methods or post-mortem sampling (Fairclough et al. 2014), but recent work has shown that recreational anglers possess the skills needed to participate in more sophisticated sampling techniques utilizing catch-and-release fishing (Williams et al. 2015).

Mark-recapture, a commonly used technique to estimate population size, can be conducted through a variety of field collection methods. In small or remote mountain lakes, hook-and-line fishing is the preferred method of sampling due to logistical problems associated with transporting gear such as electroshock units and seines (Gresswell et al. 1997). This approach also provides opportunities for skilled recreational anglers to participate in monitoring efforts as citizen scientists, providing a dual benefit to resource management agencies and the public-at-large.

The goal of this study was to use citizen science to assess the wild Coastal Rainbow Trout (*Oncorhynchus mykiss irideus*) population of Grass Valley Creek Reservoir (GVCR), a body of water that is currently under consideration for future designation under the California Heritage and Wild Trout program (M. Dege, California Department of Fish and Wildlife, personal communication). Participants collected mark-recapture data to establish a baseline population estimate, as well as condition metrics such as size and physical appearance. Many anglers already possess an interest in conservation; providing a mechanism for them to participate in a process that results in cost-effective data collection, and serves as an important interface between agency managers and stakeholders.

## Methods

*Study System.*—Behnke (1992) describes Coastal Rainbow Trout as a cold water salmonid fish species whose native range historically spanned Pacific coast streams from Alaska to Mexico. These fish exhibit both freshwater-resident and anadromous forms. Residents complete their entire lifecycle in freshwater lakes and streams, while the anadromous form, commonly called Steelhead, migrates to the ocean as a juvenile and returns to freshwater as adults to spawn. Resident Coastal Rainbow Trout typically spawn during the spring as water temperatures rise. During this time of year, the reseident trout will spawn in tributary streams and inlets (Behnke 1992). In the case of GVCR, the resident trout spawn in Grass Valley Creek as it is the lone tributary of GVCR

Grass Valley Creek Reservoir is a manmade reservoir located in eastern Trinity County, California, adjacent to the Shasta-Trinity County line and California State Route 299W. It is approximately 40 kilometers west-northwest of Redding, California, located at 40º 37' 26″N and 122º 45' 30″W (Figure 1) with a dam crest elevation of 858 meters (United States Bureau of Reclamation 2017). Historically, Grass Valley Creek supported resident and migratory populations of Coastal Rainbow Trout. The Grass Valley Creek population became landlocked by the construction of the Buckhorn Sediment Dam, which was completed in 1991 without a fish bypass structure (e.g., fish ladder). As a consequence, fish from GVCR can no longer migrate to and from the Pacific Ocean (M. Dege, California Department of Fish and Wildlife, personal communication). Currently, angling regulations allow a two fish bag limit, regardless of size, for those who wish to harvest fish from the reservoir.

*Citizen Scientist Selection and Training.*—Six citizen scientists were recruited based on their fly-fishing experience in general, and specifically, their many years experience in fishing at GVCR. Opportunities were advertised via word-of-mouth, including announcements at local fly-fishing shops. Prior to data collection, all anglers received training on how to mark, measure, and assess the fish for physical abnormalities. Fin clipping instruction was done on fish that were purchased from a local market and each citizen scientist had the opportunity to perform a fin clip. Anglers were also trained on what fork length represented and how to make the measurement.

*Field Methods.*—Field methods were designed to collect data for a continuous Schnabel mark-recapture analysis (Schnabel 1938, Carpenter et al. 2001, Pine et al. 2003, Hansen et al. 2008). The study was completed over 13 sampling days from 01 October 2016 through 29 January 2017. A seven person team, made up of citizen scientists and the lead author (D.C.H.), caught, marked, and released fish in GVCR. Anglers fished from float tubes (a type of an inner tube used by recreational anglers) with fly rods that were equipped with sinking, intermediate sinking, or floating fly lines. Anglers used flies that imitated the nymph stage of aquatic and terrestrial insects. Hook sizes varied from size 8 to 20 (4.8 mm to 1.5 mm) and were single and barbless, in accordance with California Freshwater Sport Fishing

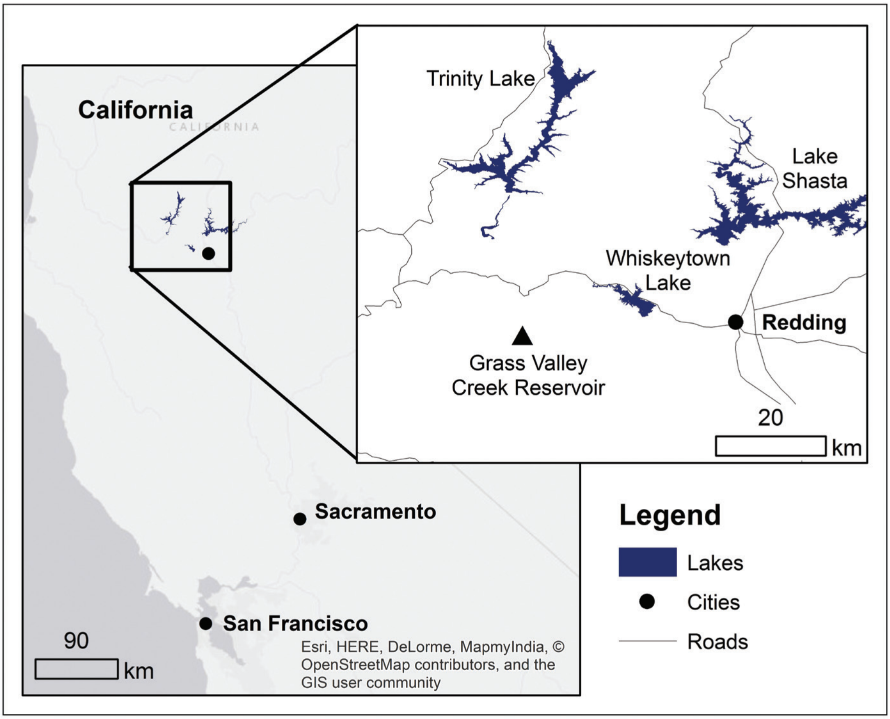


FIGURE 1.—Location map for Grass Valley Creek Reservoir, California.

Regulations (2016-2017). Landing nets were used to minimize the stress and handling time of individual fish. All fishing took place during daylight hours, generally between 0800 and 1600 hours. Each angler was required to have a California State fishing license and follow all state fishing regulations. Data were collected under California Department of Fish and Wildlife Scientific Collecting Permit #13568.

Fish sampling methods were chosen to maximize ease of data collection for citizen scientists. After capture, fish were marked by clipping their adipose fin with surgical scissors, as close to the backbone as possible, without taking any flesh from the fish. Adipose fin clips have not previously been used in GVCR, meaning that all recaptures with a clipped adipose fin originated from our study. Fish fork length was measured to the nearest ¼ inch from the tip of the nose to fork in the caudal fin, and converted to millimeters for analysis. Anglers assessed the physical appearance of each fish by counting the number of physical abnormalities present. For the purpose of our study, physical abnormalities were defined as lesions, sores, parasites, missing or damaged fins, missing or damaged eyes, gill and opercular damage, or any abnormalities caused by attempted predation. Upon completion of any mark-recapture population estimate, all captured individuals are returned to the population without being marked. Therefore, on the final day of sampling, we returned 10 fish to the water unmarked since the study had concluded.

*Analyses.*—The Schnabel function, in the fishmethods package for R-studio, was used to conduct a continuous Schnabel mark-recapture analysis that estimated population size with 95% *CI* (R Core Team 2013, Nelson 2017). The Schnabel population estimate is shown in the equation:

$$N = \frac{\sum_{i=1}^{s}(M_i C_i)}{\sum_{i=1}^{s} R_i}$$

where $s$ is the number of sampling events, $M_i$ is the number of previously marked individuals in the population at sampling event $i$, $C_i$ is the total number of fish caught during sampling event $i$, and $R_i$ is the total number of recaptures during sampling event $i$.

This method is commonly used in fisheries mark-recapture studies (Schnabel 1938, Carpenter et al. 2001, Pine et al. 2003, Hansen et al. 2008) and assumes that (1) the population is closed, (2) all fish have an equal probability of being caught, (3) marking fish does not affect their probability of recapture, (4) tags are not lost between capture events, and (5) all tags are reported during recaptures. To increase confidence that these assumptions were met, we plotted the total number of fish that had been previously marked after each sampling period against the proportion of fish in each sample that had been previously marked, and examined the linearity of this relationship using a Pearson correlation coefficient. A non-linear relationship could be caused by violations of the method's assumptions (Sutherland 2006).

Summary statistics were created to describe fish size class, condition, and catch-per-unit-effort (CPUE). Fish size class was summarized by binning the data into approximately 25 millimeter bins. Condition was calculated as the percent of fish with a given number of physical abnormalities. For these metrics, we used data recorded during the first capture. CPUE was calculated as the average number of fish caught per angler each hour.

In order to ensure consistency between citizen scientists, we excluded data from any angler whose individual CPUE fell more than one standard deviation away from the overall mean CPUE for the study. Two anglers met this criteria; thus, the results reported here reflect data collected by five anglers. We do note, however, that exclusion of these anglers had a negligible effect on our final population estimate.

## Results

During the study, 421 fish were captured. Of those, 39 fish were recaptures and 372 were marked (Table 1). These numbers were used in a continuous Schnabel mark-recapture analysis, which estimated the population size of Coastal Rainbow Trout to be 1,924 fish (95% confidence interval: 1,443-2,780). There was a linear relationship between total number of fish that had been previously marked after each sampling period and the proportion of fish in each sample that had been previously marked (Pearson Correlation: $r = 0.617$, $p = 0.025$, $n = 13$), increasing our confidence that the model's assumptions were met.

Over the course of 360 hours of fishing, the CPUE per angler was calculated as 1.17 fish per hour (Table 2). Due to variation in the number of anglers and the number of hours sampled per day, the daily average CPUE differed slightly and was calculated as 1.22 (*SD* = 0.68) fish per hour.

Total length of the fish in this study ranged from 152.4 - 457.2 mm. Mean total length of the sample population was 283.9 mm (*SD* = 57.1 mm) (Figure 2). Ninety five percent of the 382 sampled fish had no physical abnormalities. Fifteen exhibited one physical abnormality (3.93%), and two fish exhibited two physical abnormalities (0.52%). No fish had more than two physical abnormalities.

TABLE 1—Daily sampling data for the number of fish caught (Ci), recaptured (Ri), newly marked and previously marked (Mi) for the continuous Schnabel population estimate of Rainbow Trout in the Grass Valley Creek Reservoir

| | | **Population Estimate** | | |
|---|---|---|---|---|
| **Sample Date ($_i$)** | **Caught ($C_i$)** | **Recaptures ($R_i$)** | **Newly Marked** | **Previously Marked ($M_i$)** |
| 10/01/2016 | 59 | 0 | 59 | 0 |
| 10/02/2016 | 36 | 0 | 36 | 59 |
| 10/09/2016 | 44 | 5 | 39 | 95 |
| 10/15/2016 | 36 | 3 | 33 | 134 |
| 10/22/2016 | 68 | 7 | 61 | 167 |
| 10/29/2016 | 38 | 4 | 34 | 228 |
| 11/06/2016 | 36 | 2 | 34 | 262 |
| 11/11/2016 | 24 | 5 | 19 | 296 |
| 11/20/2016 | 23 | 1 | 22 | 315 |
| 12/03/2016 | 9 | 1 | 8 | 337 |
| 12/10/2016 | 14 | 4 | 10 | 345 |
| 12/17/2016 | 23 | 6 | 17 | 355 |
| 01/29/2017 | 11 | 1 | 0 | 372 |
| **Totals** | **421** | **39** | **372** | |

TABLE 2.—The catch per unit effort (CPUE) for each sampling day. CPUE was calculated as the number of fish caught per angler each hour fished.

| Date | Anglers | Hours Fished | Total Caught | CPUE |
|---|---|---|---|---|
| 10/01/2016 | 5 | 37 | 59 | 1.59 |
| 10/02/2016 | 2 | 16 | 36 | 2.25 |
| 10/09/2016 | 5 | 40 | 44 | 1.10 |
| 10/15/2016 | 2 | 14 | 36 | 2.57 |
| 10/22/2016 | 5 | 40 | 68 | 1.70 |
| 10/29/2016 | 3 | 24 | 38 | 1.58 |
| 11/06/2016 | 4 | 32 | 36 | 1.13 |
| 11/11/2016 | 4 | 32 | 24 | 0.75 |
| 11/20/2016 | 4 | 32 | 23 | 0.72 |
| 12/03/2016 | 3 | 24 | 9 | 0.38 |
| 12/10/2016 | 3 | 24 | 14 | 0.58 |
| 12/17/2016 | 3 | 24 | 23 | 0.96 |
| 01/29/2016 | 3 | 24 | 11 | 0.52 |
| **2016-2017** | **5** | **360** | **421** | |

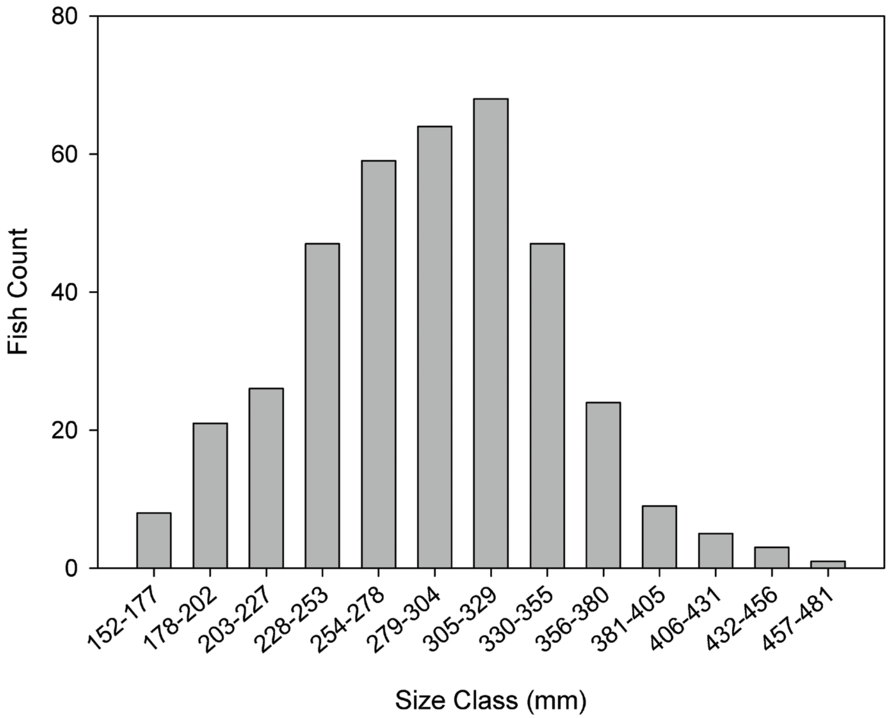


Figure 2.—Size class distribution (in millimeters) of Coastal Rainbow Trout in Grass Valley Creek Reservoir. Data from recaptures are excluded.

## Discussion

This study has provided data that can potentially aid in the management and sustainability of Grass Valley Creek Reservoir Coastal Rainbow Trout fishery. The study also demonstrates that the utilization of experienced anglers as citizen scientists can contribute to more advanced studies and improved data collection. While this study is narrow in its scope, taking place at one mid-altitude reservoir in northern California, the methods are easily applied to other lake systems making the study broad in its application.

The Schnabel population estimate has several inherent assumptions built into the model (Schnabel 1938, Sutherland 2006). First, it assumes that the population has negligible births, deaths, emigration, and immigration. We placed signs along trails and access roads asking the public to release all fish caught during the study, with the goal of reducing the number of fish leaving the population. Second, it assumes that all fish have an equal probability of being caught. A limitation of this study is that angling is an effective sampling method only for a certain range of fish sizes. In addition to being gape-limited, ontogenetic shifts in diet may mean that smaller fish are not attracted to the types of flies that were used in this study. Likewise, larger fish may shift to larger prey items to maximize energetic intake relative to foraging effort (Townsend and Winfield 1985). Because of this, our population estimate likely estimates a limited number of size classes. Third, the Schnabel estimate assumes that marking fish does not affect their probability of recapture. In order to decrease behavioral changes that may affect this assumption, we took steps to minimize stress and handling time. Fin clipping was conducted as quickly as possible to minimize air exposure. In circumstances where handling time may have been increased, fish were placed in the water to rest and recover prior to completion of marking and data collection. Fourth, the model assumes that tags are not lost between capture events. Since our marking method was the removal of the adipose fin, we are confident that this assumption was met. Finally, it assumes that all tags are reported during recapture. Experienced anglers can easily recognize fin clips, and our team was actively monitoring clips of recaptured fish for signs of infection. Given this, it is unlikely that any marked fish went unreported during resampling.

Thompson and Blankenship (2011) examined adipose fin regeneration after clipping in Coho salmon (*Oncorhynchus kisutch),* a species that is closely related to Coastal Rainbow Trout. They found that when the adipose fin was completely removed, it showed no regeneration after 24 months. Because of this, adipose fin clips cannot be reliably used in subsequent mark-recapture studies at GVCR because it would not be possible to determine how many fish with a missing adipose fin are in the reservoir at the onset of the study. Therefore, we recommend that future studies at GVCR utilize a different marking method, such as a hole punch to the caudal fin. Previous work has shown that caudal hole-punches regenerate over time, allowing differentiation between marking events from different seasons (Allison 1963).

A strategic goal of the California Fish and Game Commission, which established the California Heritage and Wild Trout Program, is to "Increase public participation and representation in Commission decision-making processes and operations." Citizen science engages the public and increases stewardship (Dickinson et al. 2012), making it an excellent way to support this goal. However, there has been some concern that data collected by citizen scientists is more error-prone than data collected by professional scientists. For example, several studies on volunteer-based monitoring programs have found a "learner" effect, where the quality of the data collected by citizen scientists improves over time (Sauer et al. 1994, Kendall et al. 1996, Jiguet 2009). Other studies have found that datasets are largely reliable when citizen scientists are given proper training (Done et al. 2017, Palmer et al. 2017). We argue that experienced recreational anglers, such as the citizen scientists who participated in our study, are likely to have surpassed this learning curve because they already have many hours of experience angling, identifying species, and handling fish. We chose a simple and inexpensive marking technique, fin clipping, and the citizen scientists received training on this methodology prior to the onset of sampling, likely leading to a decrease in errors in our population estimation. Another benefit that comes with citizen science is that it can help offset the budget and resource constraints that plague many monitoring programs. Gardiner et al. (2012) did a cost-benefit analysis of implementing citizen science programs. They found that, despite requiring an initial investment, citizen science was more cost effective per dollar than traditional data collection methods over time. The authors acknowledge that there may be an increase in data collection errors but argue that, in many cases, this is counterbalanced by the ability to collect a larger dataset in a cost-effective manner.

CDFW conducted a *Fish for Science* program at GVCR from 1994-1997, and again in 2011, which used CPUE of participants as an estimate of fish abundance. This approach assumes a proportional relationship between CPUE and overall fish abundance, but has been criticized as a metric for estimating fish abundance (Harley et al. 2001, Maunder et al. 2006). However, it is still widely used in assessing fishery stocks in large ocean basins (McCluskey and Lewison 2008). While most published criticisms of CPUE focus on ocean systems, some criticisms are applicable to freshwater systems. Specifically, CPUE can easily be influenced by environmental conditions that influence fish appetite and behavior, such as seasonal variations or differences between years (Lucas and Baras 2000, Hilborn and Walters 2013), making the validity of comparing different sampling periods questionable. Despite this, we believe that CPUE can be a valuable tool to engage citizen scientists as long as it is interpreted with these limitations in mind. While the results from mark-recapture methods such as the Schnabel estimate are not readily accessible to anglers during the sampling period, CPUE provides anglers with a real-time, albeit rough, metric that can help keep them engaged throughout the study.

We recommend that citizen scientists be incorporated into future fish population studies when possible. Incorporating experienced anglers as citizen scientists facilitated a larger dataset and met the goals of the California Fish and Game Commission. Our straightforward methods were chosen so that they were easily understood and applied by citizen scientists. These experienced anglers were able to collect important data on a fish population, while taking care to reduce handling time and stress to fish. The methods employed make this study reproducible in the future at GVCR, as well as other diverse lake habitats across California.

## Acknowledgments

We thank E. Martin, S. Martin, M. Peterson, D. Roberts, A. Suniga, and N. Whichello for donating their time to aid in the collection of the data. M. Dege, Senior Fisheries Biologist for the Heritage and Wild Trout Program, acted as a technical advisor for this project, as well as a reviewer of the report throughout the course of this study. His input and encouragement were greatly appreciated. L Hiney provided logistical support. D. Stompe provided editorial comments on an earlier draft of the manuscript.

## Literature Cited

Allison, Leonard N. 1963. Marking fish with a paper hole punch. Institute for Fisheries Research, Michigan Department of Conservation 1656:1-4.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society monograph No. 6.

California Department of Fish and Wildlife. 2017a. Heritage and Wild Trout Program [cited 04 December 2017]. Available from: https://www.wildlife.ca.gov/Conservation/Inland-Fisheries/Wild-Trout

California Department of Fish and Wildlife. 2017b. Designated Wild and Heritage Trout Waters [cited 04 December 2017]. Available from: https://www.wildlife.ca.gov/Fishing/Inland/Trout-Waters

California Department of Fish and Wildlife. 2017c. Definitions of "Wild Trout Water" and "Heritage Trout Water" [cited 04 December 2017]. Available from: https://www.wildlife.ca.gov/Fishing/Inland/Trout-Waters/Definitions

Carpenter, S. R., J. J. Coleman, J. R. Hodgson, J. F. Kitchell, M. L. Pace, D. Bade, K. L. Cottingham, T. E. Essington, J. N. Houser, and D. E. Schindler. 2001. Trophic cascades, nutrients, and lake productivity: whole-lake experiments. Ecological Monographs 71:163-186.

Dickinson, J. L., J. Shirk, D. Bonter, R. Bonney, R. L. Crain, J. Martin, T. Phillips, and

K. Purcell. 2012. The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment 10:291-297.

Done, T., C. Roelfsema, A. Harvey, L. Schuller, J. Hill, M.L. Schläppy, A. Lea, A. Bauer-Civiello, and J. Loder. 2017. Reliability and utility of citizen science reef monitoring data collected by Reef Check Australia, 2002-2015. Marine Pollution Bulletin 117:148-155.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A. H. Prieur-Richard, D. Soto, M. L. Stiassny, C.A. Sullivan. 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81:163-182.

Fairclough, D. V., J. I. Brown, B. J. Carlish, B. M. Crisafulli, and I. S. Keay. 2014. Breathing life into fisheries stock assessments with citizen science. Scientific Reports 4:7249.

Gardiner, M. M., L. L. Allee, P. M. Brown, J. E. Losey, H. E. Roy, and R. R. Smyth. 2012. Lessons from lady beetles: accuracy of monitoring data from US and UK citizen-science programs. Frontiers in Ecology and the Environment 10:471-476.

Gresswell, R. E. , W. J. Liss, G. A. Lomnicky, E. K. Deimling, R. L. Hoffman, and T. Tyler. 1997. Using mark-recapture methods to estimate fish abundance in small mountain lakes. Northwest science 71:39-44.

Hansen, M. J., N. J. Horner, M. Liter, M. P. Peterson, and M. A. Maiolie. 2008. Dynamics of an increasing lake trout population in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 28:1160-1171.

Harley, S. J., R. A. Myers, and A. Dunn. 2001. Is catch-per-unit-effort proportional to abundance? Canadian Journal of Fisheries and Aquatic Sciences 58:1760-1772.

Hilborn, R. and C. J. Walters, editors. 2013. Quantitative fisheries stock assessment: choice, dynamics and uncertainty. Springer Science & Business Media, New York, USA.

Jiguet, F. 2009. Method learning caused a first-time observer effect in a newly started breeding bird survey. Bird Study 56:253-258.

Katz, J., P. B. Moyle, R. M. Quiñones, J. Israel, and S. Purdy. 2013. Impending extinction of salmon, steelhead, and trout (Salmonidae) in California. Environmental Biology of Fishes 96:1169-1186.

Kendall, W. L., B. G. Peterjohn, and J. R. Sauer. 1996. First-time observer effects in the North American Breeding Bird Survey. The Auk 113:823-829.

Lucas, M. C. and E. Baras. 2000. Methods for studying spatial behaviour of freshwater fishes in the natural environment. Fish and Fisheries 1:283-316.

Mantyka-Pringle, C. S., T. G. Martin, and J. R. Rhodes. 2012. Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. Global Change Biology 18:1239-1252.

Maunder, M. N., J. R. Sibert, A. Fonteneau, J. Hampton, P. Kleiber, and S. J. Harley. 2006. Interpreting catch per unit effort data to assess the status of individual stocks and communities. ICES Journal of Marine Science 63:1373-1385.

McCluskey, S. M. and R. L. Lewison. 2008. Quantifying fishing effort: a synthesis of current methods and their applications. Fish and Fisheries 9:188-200.

Moyle, P. B. and J. E. Williams. 1990. Biodiversity Loss in the temperate zone: decline of the native fish fauna of California. Conservation Biology 4:275-284.

Moyle, P. B,. J. D. Kiernan, P. K. Crain, and R. M. Quiñones. 2013. Climate change vulnerability of native and alien freshwater fishes of California: a systematic assessment approach. PLOS ONE 8:e63883.

Nelson, G. A. 2017. Fishery science methods and models in R. R package version 1.10-4.

Palmer, J. R. B., A. Oltra, F. Collantes, J. A. Delgado, J. Lucientes, S. Delacour, M. Bengoa, R. Eritja, and F. Bartumeus. 2017. Citizen science provides a reliable and scalable tool to track disease-carrying mosquitoes. Nature Communications 8:916.

Pine, W. E., K. H. Pollock, J. E. Hightower, T. J. Kwak, and J. A. Rice. 2003. A review of tagging methods for estimating fish population size and components of mortality. Fisheries 28:10-23.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available from: http://www.R-project.org/

Sauer, J. R., B. G. Peterjohn, and W. A. Link. 1994. Observer differences in the North American Breeding Bird Survey. The Auk 111:50-62.

Schnabel, Z. E. 1938. The estimation of total fish population of a lake. The American Mathematical Monthly 45:348-352.

Sutherland, W. J, editor. 2006. Ecological census techniques: a handbook. Cambridge University Press. Cambridge, United Kingdom.

Thompson, D. A. and H. L. Blankenship. 2011. Regeneration of adipose fins given complete and incomplete clips. North American Journal of Fisheries Management 17:467-469

Townsend, C. R. and I. J. Winfield. 1985. The application of optimal foraging theory to feeding behaviour in fish. Pages 67-98 *in* Fish Energetics. Springer, Dordrecht, Netherlands.

Tulloch, A. I. T., H. P. Possingham, L. N. Joseph, J. Szabo, and T. G. Martin. 2013. Realizing the full potential of citizen science monitoring programs. Biological Conservation 165:128-138.

United States Bureau of Reclamation. 2017. Projects & Facilities: Dams: Buckhorn Dam [cited 2017 Dec 4]. Available from: https://www.usbr.gov/projects/index.php?id=31,

Williams, S. M., B. J. Holmes, and J. G. Pepperell. 2015. The novel application of non-lethal citizen science tissue sampling in recreational fisheries. PLOS ONE 10:e0135743.

Woodward, G., D. M. Perkins, and L. E. Brown. 2010. Climate change and freshwater ecosystems: impacts across multiple levels of organization. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences 365:2093-2106.

Yoshiyama, R.M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of chinook salmon in the central valley region of California. North American Journal of Fisheries Management 18:487-521.

*Received: 16 December 2017*
*Accepted: 03 May 2018*
*Associate Editor was J. Weaver*