Mathematically Modeling How Trapping Regimes that Target Specific Crayfish Life Stages Impact Removal Efficacy

PEPPERDINE
Summer Undergraduate Research in Biology

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Introduction

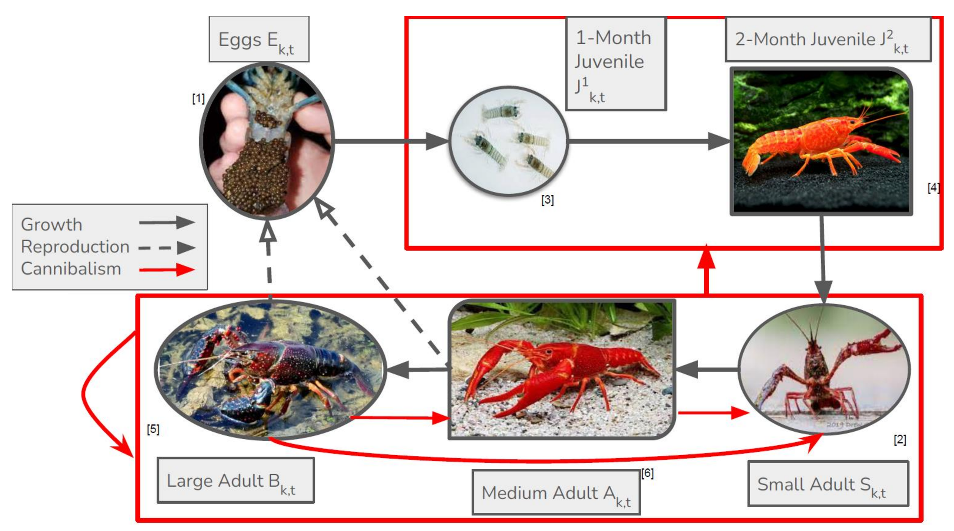
The red swamp crayfish, *Procambarus clarkii*, is an invasive species introduced into several streams within the Santa Monica Mountains in Southern California. Crayfish predation decimates native aquatic species. Thus, the Mountains Restoration Trust (MRT) and Environmental Restoration Group (ERG) have worked to remove crayfish through regular trapping in Malibu Creek.

To aid conservation efforts, former students William Milligan and Dev Patel developed mathematical models of crayfish removal efficacy. Milligan created a differential equation model of how crayfish removal affects local newt populations. Patel expanded Milligan's crayfish model by creating a discrete model of the crayfish life cycle that newly accounts for cannibalism but is not yet parameterized to stream data.

We expand Patel's model to better predict the efficacy of crayfish removal efforts in the Santa Monica Mountains. We divide crayfish based upon life stage and total length: eggs, two monthly juvenile stages, small (4-5 cm) non-reproductive adults, medium (6-7 cm) adults, and large (8+ cm) adults.

We construct and parametrize this preliminary predictive model of crayfish population levels with and without trapping. We use literature and crayfish removal data provided by MRT from the Middle Las Virgenes (MLV) portion of Malibu Creek. We evaluate how the crayfish population changes over time and examine the sensitivity of population predictions to crayfish survivorship. We determine the best crayfish life stages to trap to most efficiently decrease crayfish population size.

Crayfish Life Cycle



Research Question

Which crayfish life stages should be removed to most effectively reduce crayfish presence in Middle Las Virgenes Creek?

Parameters

Initial Conditions (number of crayfish in month k = 1 and year t = 0):

Eggs	1-Month Juveniles	2-Month Juveniles	Small Adults	Medium Adults	Large Adults
$E_{1,0}$ = 298560	$J^1_{1,0}$ = 16000	$J^2_{1,0}$ = 8000	$S_{1,0}$ = 8000	$A_{1,0}$ = 4000	$B_{1,0}$ = 4000

Param.	Description	Value/Units	Source
λ	Percent of females that reproduce during a month	.25	1
b_A	Average number of eggs produced by a medium reproductive female	100 eggs/crayfish	1
b_B	Average number of eggs produced by a large reproductive female	500 eggs/crayfish	1
σ_E	Monthly survivorship of eggs	.65	7
σ_J	Monthly survivorship of juveniles	.7	6
σ_S	Monthly survivorship of small adults	.65	5
σ_A	Monthly survivorship of medium adults	.8	8
σ_B	Monthly survivorship of large adults	.49	4
μ_J	Likelihood that a juvenile is cannibalized by an adult	1.79×10^{-6}	Fit
μ_S	Likelihood that a small adult is cannibalized by an adult	3.98×10^{-6}	Fit
μ_A	Likelihood that a medium adult is cannibalized by an adult	6.90×10^{-8}	Fit
μ_B	Likelihood that a large adult is cannibalized by an adult	8.32×10^{-7}	Fit
T_J	Number of juveniles that can be removed by human effort	Based on trap	MRT, 2
T_S	Number of small adults that can be removed by human effort	Based on trap	MRT, 2
T_A	Number of medium adults that can be removed by human effort	Based on trap	MRT, 2
T_B	Number of large adults that can be removed by human effort	Based on trap	MRT, 2
ξ_J	Percent of juveniles who are available to be trapped	.5	
ξ_S	Percent of small adults who are available to be trapped	.3	Fit
ξ_A	Percent of medium adults who are available to be trapped	.4023	Fit
ξ_B	Percent of large adults who are available to be trapped	.6	5
τ_S	Percent of small adults who grow into medium adults per month	.3	Fit
τ_A	Percent of medium adults who grow into large adults per month	.4913	Fit
X_k	Determines if trapping occurs during the month	0 or 1	

Size-Structured Crayfish Model

k = Month t = Year

Cannibalism Trapping

Eggs
$$E_{k,t} = \lambda\left(\frac{1}{2}b_A A_{k,t} + \frac{1}{2}b_B B_{k,t}\right)$$

1-Month Juveniles
$$J^1_{k,t} = \sigma_E E_{k-1,t}$$

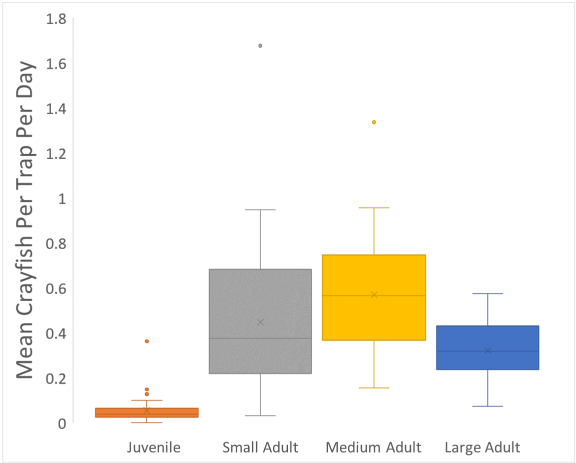
2-Month Juveniles
$$J^2_{k,t} = \sigma_J\left(J^1_{k-1,t} - \mu_J J^1_{k-1,t} N^S_{k-1,t} - X_k \min(T_J, \xi_J(J^1_{k-1,t} - \mu_J J^1_{k-1,t} N^S_{k-1,t}))\right)$$

Small Adults
$$S_{k,t} = \sigma_J\left(J^2_{k-1,t} - \mu_J J^2_{k-1,t} N^S_{k-1,t} - X_k \min(T_J, \xi_J(J^2_{k-1,t} - \mu_J J^2_{k-1,t} N^S_{k-1,t}))\right) + \sigma_S(1-\tau_S)\left(S_{k-1,t} - \mu_S S_{k-1,t} N^S_{k-1,t} - X_k \min(T_S, \xi_S(S_{k-1,t} - \mu_S S_{k-1,t} N^S_{k-1,t}))\right)$$

Medium Adults
$$A_{k,t} = \sigma_S \tau_S\left(S_{k-1,t} - \mu_S S_{k-1,t} N^S_{k-1,t} - X_k \min(T_S, \xi_S(S_{k-1,t} - \mu_S S_{k-1,t} N^S_{k-1,t}))\right) + \sigma_A(1-\tau_A)\left(A_{k-1,t} - \mu_A A_{k-1,t} N^A_{k-1,t} - X_k \min(T_A, \xi_A(A_{k-1,t} - \mu_A A_{k-1,t} N^A_{k-1,t}))\right)$$

Large Adults
$$B_{k,t} = \sigma_A \tau_A\left(A_{k-1,t} - \mu_A A_{k-1,t} N^A_{k-1,t} - X_k \min(T_A, \xi_A(A_{k-1,t} - \mu_A A_{k-1,t} N^A_{k-1,t}))\right) + \sigma_B\left(B_{k-1,t} - \mu_B B_{k-1,t} N^B_{k-1,t} - X_k \min(T_B, \xi_B(B_{k-1,t} - \mu_B B_{k-1,t} N^B_{k-1,t}))\right)$$

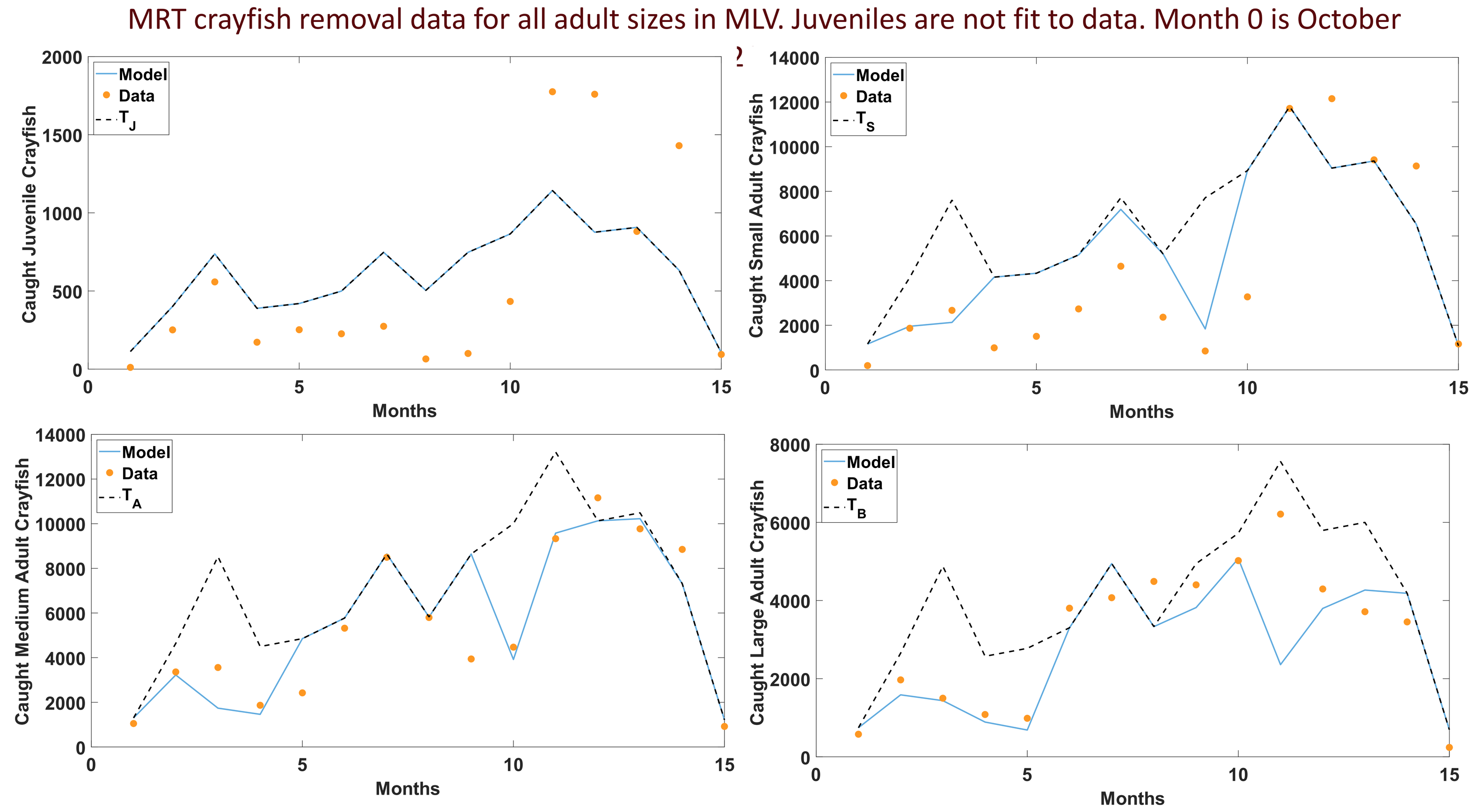
$$N^S_{k,t} = S_{k,t} + A_{k,t} + B_{k,t}$$
$$N^A_{k,t} = A_{k,t} + B_{k,t}$$
$$N^B_{k,t} = B_{k,t}$$



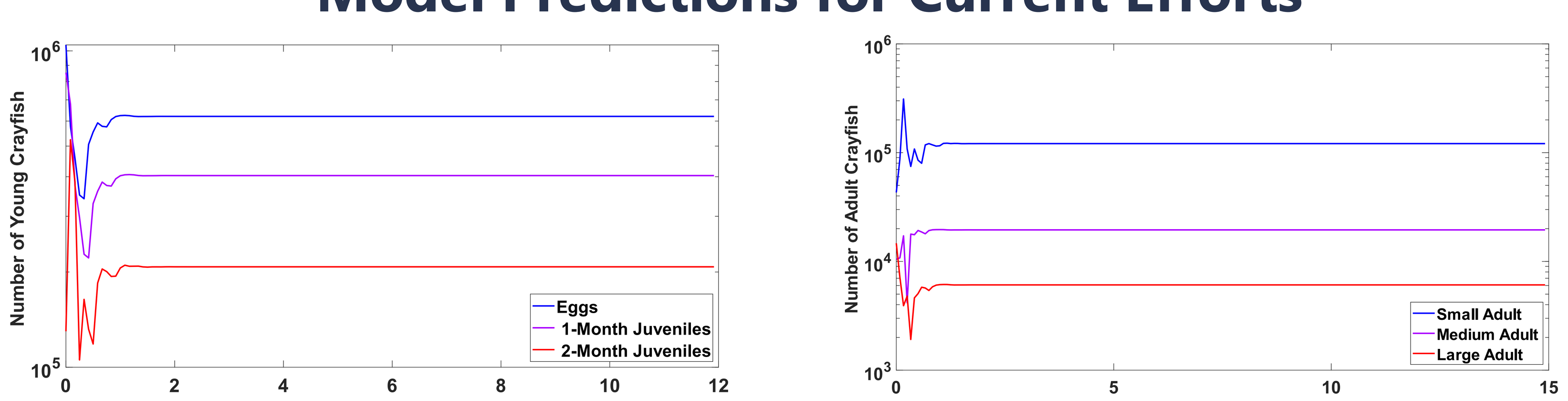
Right: MRT removal data from MLV

Model Fit to MRT Removal Data

Model fit of crayfish availability (ξ_S, ξ_A), cannibalism (μ_J, μ_S, μ_A, μ_B), and body growth (τ_S,τ_A) parameters to MRT crayfish removal data for all adult sizes in MLV. Juveniles are not fit to data. Month 0 is October

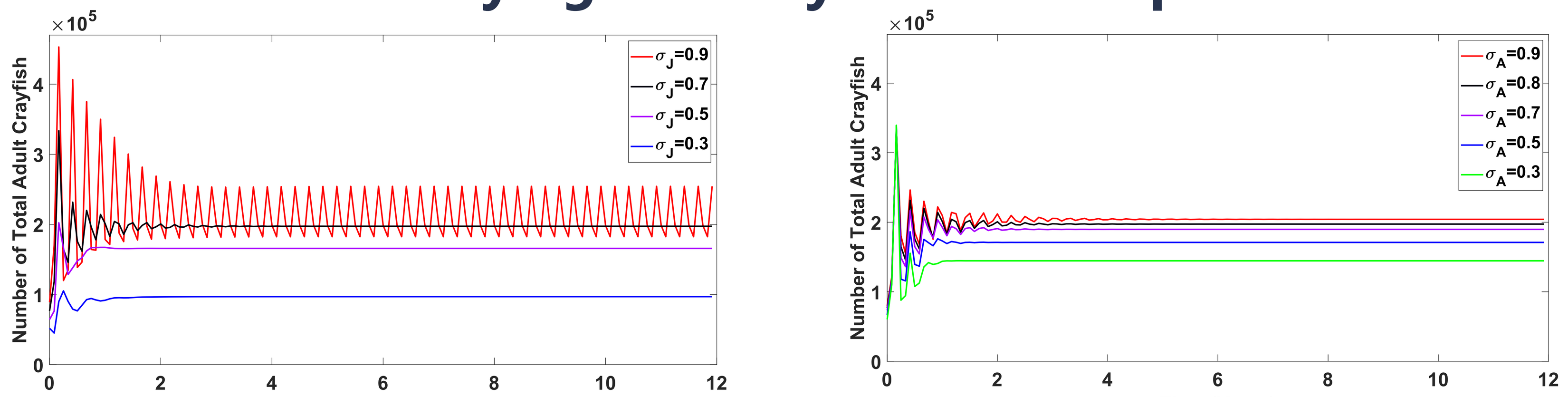


Model Predictions for Current Efforts



Model predictions for baseline parameters with sustained trapping:
Current efforts are not sufficient to eradicate crayfish in the Santa Monica Mountains.

Varying Monthly Survivorship

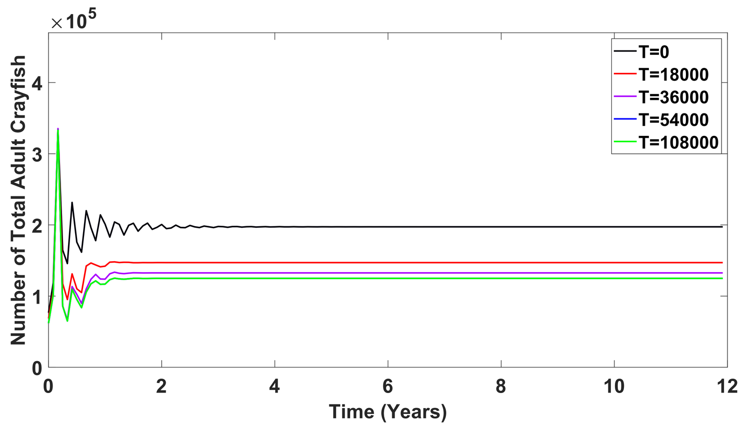


Model results without trapping are highly sensitive to monthly juvenile survivorship (σ_J) and less sensitive to medium adult survivorship (σ_A).

Trap Only Adults

Trapping exclusively adults reduces crayfish populations but not to extinction.

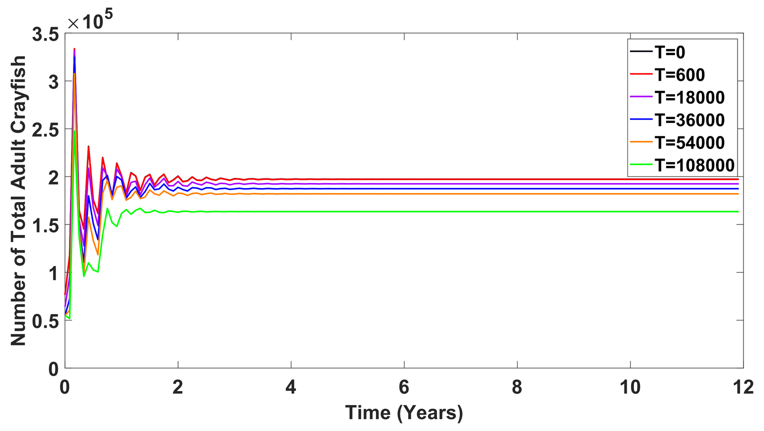
T: Total removed crayfish per month



Trap Only Juveniles

Trapping exclusively juveniles has minimal effect on reducing crayfish populations.

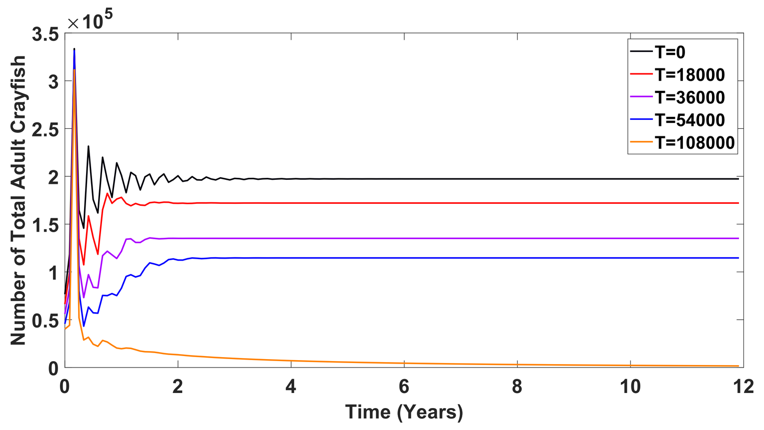
T_J: Total removed juveniles per month



Trap With Smaller Mesh Sizes

Modeling predicts smaller mesh traps are necessary to reduce crayfish populations by preventing crayfish maturation.

Here, we assume T_J is half of total removed crayfish, T.



Conclusions

- Preliminary model predictions suggest sustained trapping of adults reduces the crayfish population.
- Traps with smaller mesh size that catch more juveniles are needed to fully reduce the crayfish population to local extinction.
- Better estimates of survivorship of young crayfish would improve accuracy of model predictions.
- Preliminary parameterization suggests the carrying capacity of adult crayfish is about 200,000 crayfish in MLV.

Future Directions

- Model fits are preliminary and require further refinement against MRT and ERG data.
- Validate model against crayfish presence data.
- Incorporate crayfish migration due to high stream flow.

References

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[4] Aquatic Arts [5] H. Rashid [6] Chris Lukhaup

Acknowledgements

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