**ATTACHMENT C** ***EVOSTC Annual Project Report Form***

Form Rev. 10.3.14

*Please refer to the Reporting Policy for all reporting due dates and requirements.

**1. Program Number:** *See*, Reporting Policy at III (C) (1).

14120111-Q

**2. Project Title:** *See*, Reporting Policy at III (C) (2).

PWS Herring Program: Modeling the population dynamics of Prince William Sound herring.

**3. Principal Investigator(s) Names:** *See*, Reporting Policy at III (C) (3).

Trevor A. Branch

**4. Time Period Covered by the Report:** *See*, Reporting Policy at III (C) (4).

1 February 2014 to 31 January 2015

**5. Date of Report:** *See*, Reporting Policy at III (C) (5).

February 2015

**6. Project Website (if applicable):** *See*, Reporting Policy at III (C) (6).

http://pwssc.org/research/fish/pacific-herring/

**7. Summary of Work Performed:** *See*, Reporting Policy at III (C) (7).

In the past year the revised Bayesian assessment model was completed, a MS defense scheduled for Melissa Muradian, and a new graduate student John Trochta taken on to continue the modeling project. The status of the four projects is as follows: Bayesian model completed; value of survey information drafted and being finalized; meta-analysis of global herring populations started with some intriguing preliminary results; and the final project, examining hypotheses for the decline of PWS herring, is scheduled for 2016-17.

**Bayesian assessment model**: a major milestone was reached with the completed development of a an age-structured stock assessment for Prince William Sound herring, that can be used to supplement the ADF&G assessment using the ASA model. The revised model returns results that are similar to the ADF&G model for 2013 biomass estimates, but uses likelihoods to internally weight different datasets instead of least-squares minimization. In addition, a Bayesian framework is employed from within AD Model Builder, which allows for uncertainty to be automatically calculated from the Bayesian posteriors. The implications are that ADF&G could choose management rules that directly incorporate uncertainty, in deciding how conservative they should be in opening the herring fishery in the future.

**Key results of the Bayesian model**: the Bayesian model provides good fits to the available time series of data (Fig. 1), and age composition data from the fishery and spawn survey (Fig. 2). Estimated pre-fishery biomass in 2013 was 19,300 metric tonnes (Fig. 3), just below the threshold for opening the fishery (22,000 short tons = 19,958 mt). The 95% probability interval was 11,400-32,400 mt, and there was an estimated 55% probability of biomass being below the threshold for opening the fishery. The last year of medium recruitment was in 2002, since then, recruitment at age-3 has been between 9 and 103 million fish, compared to recruitment of 117 to 1234 million fish in every year from 1980 to 1988. Taken as a whole, the model confirms the ADF&G assessment that the fishery should not be reopened, and that biomass and recruitment have been low for more than a decade now.

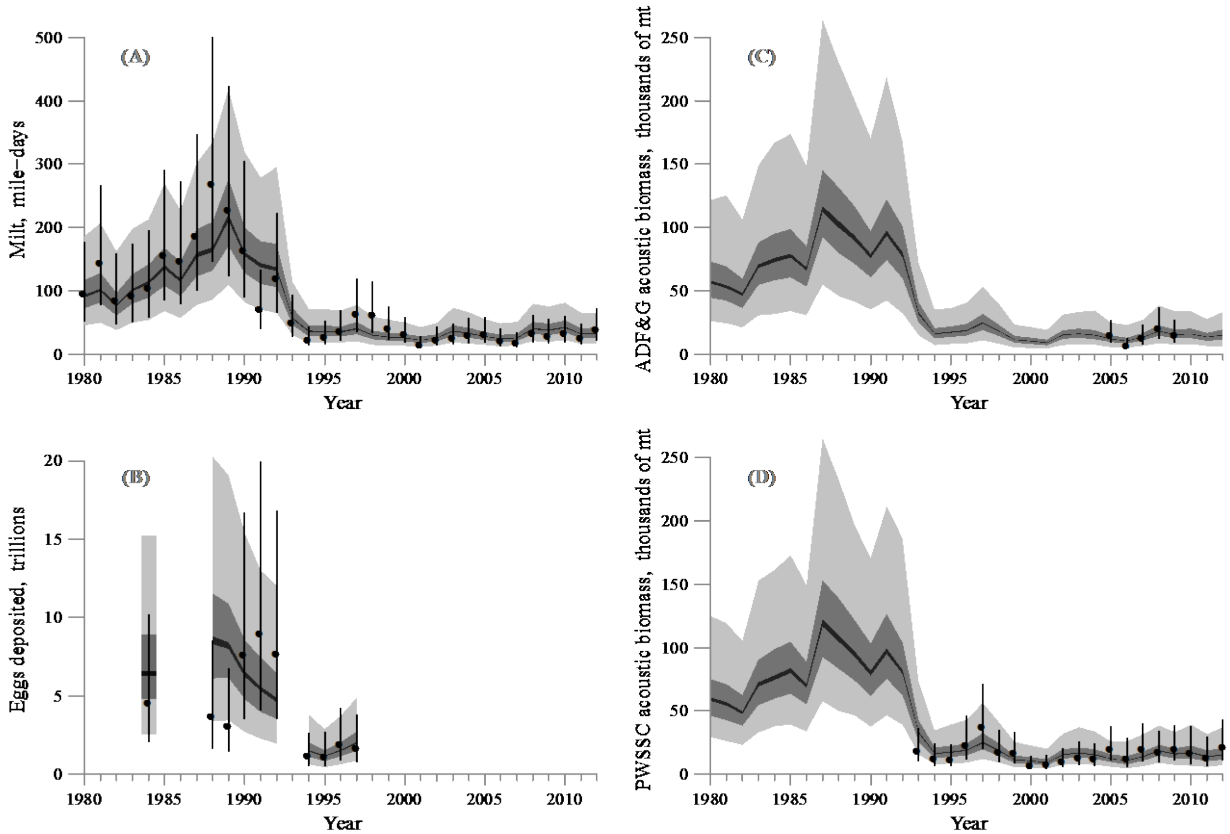


Fig 1. Model estimates fitted to the four time series of abundance estimates (1980–2012): (A) mile-days of milt, (B) egg deposition surveys, (C) ADF&G hydroacoustic estimates, and (D) PWSSC hydroacoustic estimates. The solid circles and lines represent the mean and 95% confidence intervals of the data (plus additional variance estimated by the model); the shaded polygons represent the respective posterior predictive intervals (light gray = 95% interval, darker gray = 50% interval, black = 5% interval). Source: draft MS thesis, M.L. Muradian.

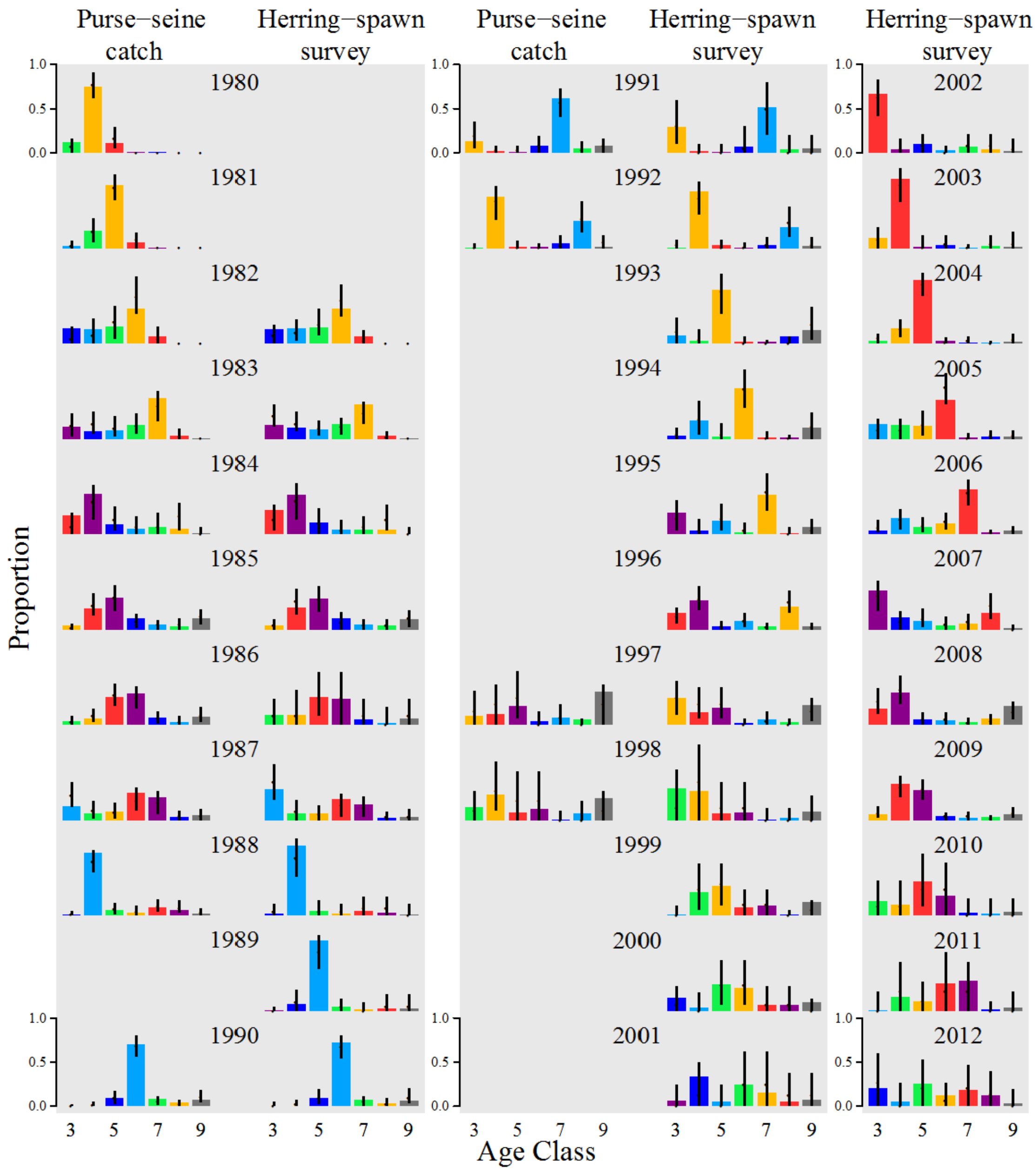


Fig. 2 Model fits to the two sets of age-composition data used: proportion of catch-at-age from the purse-seine fishery and age-composition proportions from the ADF&G herring-spawn survey. Colored bars denote data, colors track individual cohorts through time, and points show posterior median with bars showing the 95% posterior intervals. No compositions are shown for years when the spring fishery was closed (1989, 1993–1996, and after 1998). Source: draft MS thesis, M.L. Muradian.

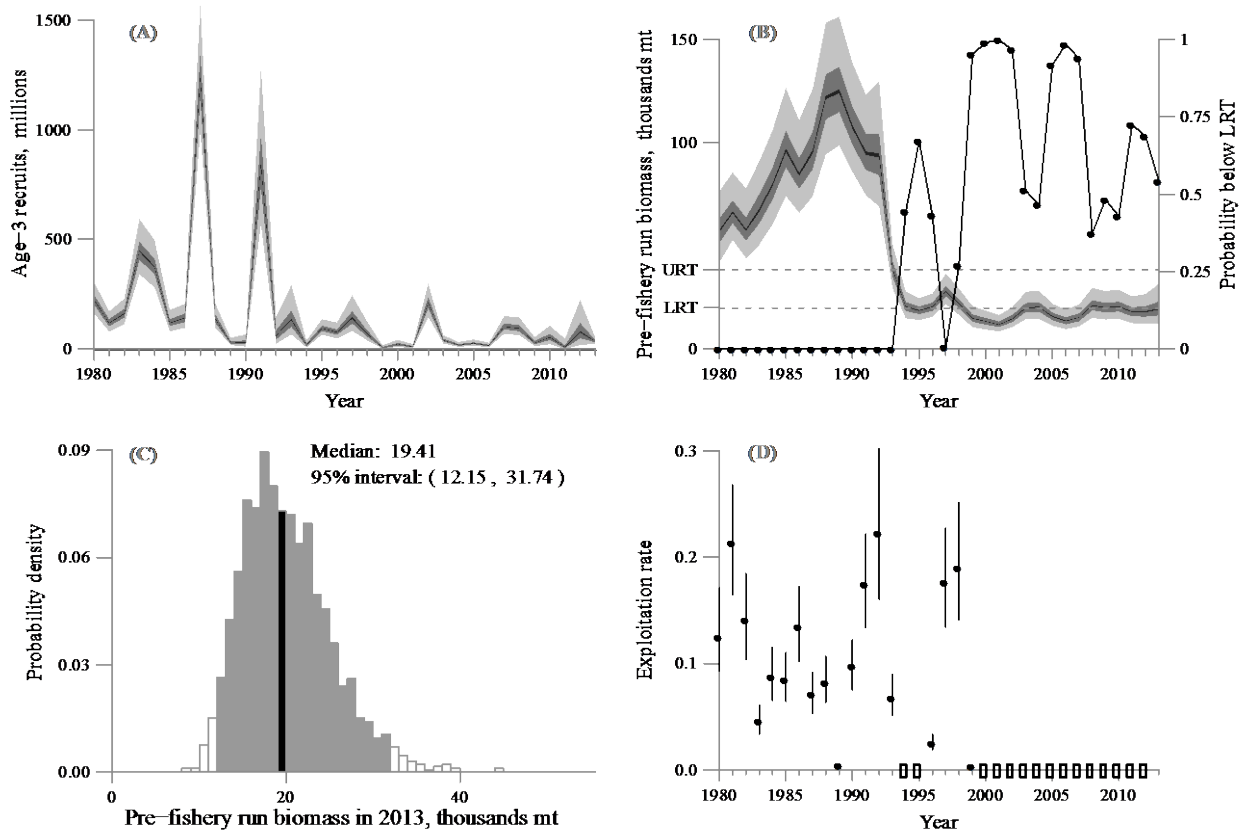


Fig. 3 The panels show (A) estimated recruitment at age-3 (posterior intervals; light gray = 95% interval, darker gray = 50% interval, black = 5% interval), (B) estimated pre-fishery biomass (posterior intervals; light gray = 95% interval, darker gray = 50% interval, black = 5% interval) and the probability that pre-fishery biomass is below the lower regulatory threshold (LRT) of 22,000 short tons (19,958 mt) (connected black points) with the upper regulatory threshold (URT: 42,500 short tons ≈ 38,555 mt) shown for reference, (C) posterior distribution of estimated pre-fishery biomass for 2013 with the 95% credible interval (light grey) and the median (black) shown, and (D) posterior median exploitation rates (black points) with 95% posterior intervals (segments) – open points show fishery closures. Source: draft MS thesis, M.L. Muradian.

**Value of surveys**: the revised Bayesian model is being used to determine which surveys are the most valuable for obtaining precise estimates of abundance. The model has been with multiple iterations (for each iteration, a different set of data are simulated and then fit with the model) for 7 scenarios. In the base scenario, all data are included in the assessment. For the other scenarios, data from a particular survey or data collection type, are omitted. The predictions are that estimated biomass should have broader uncertainty intervals and be more biased, when data types are left out, compared to the base scenario. The resulting deterioration in precision and bias represents a trade-off with the cost of the survey, allowing the determination of which survey provides the greatest improvement in the model for the lowest cost. Results are expected in March 2015.

**Meta-analysis of herring populations**: the question addressed here is whether PWS herring have collapsed and failed to recover for an unusually long period of time. Thanks to the help of Tim Essington, we have been able to analyze stock assessments for 29 herring stocks around the world. Initial analysis suggests that the 16 year long time period during which PWS herring remains under 20% of maximum biomass, is unusually lengthy, and should only occur in about 1% of all time intervals that long. These results are likely to change as we expand the compilation, add survey data for stocks without assessments, and focus on including stocks that have collapsed and not recovered (and may not have recent stock assessments).

**Alternate hypotheses for PWS herring decline**: work on this section of the project is scheduled for 2016.

**Personnel**: Melissa Muradian is expected to defend her MS thesis in March 2015. John Trochta has been taken on to join in the project and work on the herring meta-analysis and in examining hypotheses for the decline of PWS herring.

**Future directions**: it is anticipated that the model will be extended back in time to cover years prior to 1980, and extended to cover age groups 0, 1, and 2. This would assist in modeling hypotheses about over-winter survival, and correlates between environmental covariates and subsequent recruitment. In addition, this will allow for explicit fitting to the new time series of aerial surveys of juvenile herring conducted by Scott Pegau. This work may have funding implications since this was not explicitly envisaged in the original proposal.

## 8. Coordination/Collaboration: *See,* Reporting Policy at III (C) (8).

a) Coordination with Scott Pegau for data interpretation and oceanographic hypotheses.

Close coordination with Moffitt and Paul Hershberger to revise the indices of disease incorporated in the model.

Student Muradian participated in the hydroacoustic surveys in 2014 to better understand data collection and coordinate data-model interactions

Inclusion of weight-at-age, sex ratios, hydroacoustic surveys (ADF&G and PWSSC), mile-days of milt survey, spawner-egg survey, and other data collected during the herring program, involving too many people to name individually.

b) No coordination with other EVOSTC funded projects

c) Close coordination with Steven Moffitt of ADF&G to include the data collected by ADF&G for the ASA Model, sharing of model code and results of the Bayesian model.

## 9. Information and Data Transfer: *See,* Reporting Policy at III (C) (9).

**Publications**: A popular article was written by Melissa Muradian for Delta Sound Connections in 2014: “Herring: How much information does a population model need?”

Six peer-reviewed publications were coauthored by PI Branch or student Muradian on broader issues related to recruitment, fisheries status, or fisheries stock assessment simulation methods, although none focused solely on Prince William Sound herring:

Hilborn, R., D. J. Hively, O. P. Jensen, and T. A. Branch*. 2014. The dynamics of fish populations at low abundance and prospects for rebuilding and recovery. ICES Journal of Marine Science 71:2141-2151.

Hurtado-Ferro, F., C. S. Szuwalski, J. L. Valero, S. C. Anderson, C. J. Cunningham, K. F. Johnson, R. Licandeo, C. R. McGilliard, C. C. Monnahan, M. L. Muradian*, K. Ono, K. A. Vert-Pre, A. R. Whitten, and A. E. Punt. 2015. Looking in the rear-view mirror: bias and retrospective patterns in integrated, age-structured stock assessment models. ICES Journal of Marine Science 72:99-110.

Johnson, K. F., C. C. Monnahan, C. R. McGilliard, K. A. Vert-pre, S. C. Anderson, C. J. Cunningham, F. Hurtado-Ferro, R. R. Licandeo, M. L. Muradian*, K. Ono, C. S. Szuwalski, J. L. Valero, A. R. Whitten, and A. E. Punt. 2015. Time-varying natural mortality in fisheries stock assessment models: identifying a default approach. ICES Journal of Marine Science 72:137-150.

Ono, K., R. Licandeo, M. L. Muradian*, C. J. Cunningham, S. C. Anderson, F. Hurtado-Ferro, K. F. Johnson, C. R. McGilliard, C. C. Monnahan, C. S. Szuwalski, J. Valero, K. A. Vert-Pre, A. R. Whitten, and A. E. Punt. 2015. The importance of length and age composition data in statistical age-structured models for marine species. ICES Journal of Marine Science 72: 31-43.

Stachura, M. M., T. E. Essington, N. J. Mantua, A. B. Hollowed, M. A. Haltuch, P. D. Spencer, T. A. Branch*, and M. J. Doyle. 2014. Linking Northeast Pacific recruitment synchrony to environmental variability. Fisheries Oceanography 23:389-408

Szuwalski, C. S., K. A. Vert-pre, A. E. Punt, T. A. Branch*, and R. Hilborn. 2015. Examining common assumptions about recruitment: a meta-analysis of recruitment dynamics for worldwide marine fisheries. Fish and Fisheries doi:10.1111/faf.12083

**Presentations**: Talks on the work conducted included two presentations for the PWS Herring PI Meetings in March 2014 and in November 2014; an internal University of Washington talk to the QERM program; an international conference presentation at the International Marine Conservation Congress in Glasgow, Scotland, August 2014; a talk at the Alaska Marine Science Symposium in January 2015; and a project overview presentation to the EVOSTC Long-Term Programs' Science Overview Workshop 6 February 2015.

**Data transfer**: The current code for the Bayesian model is available for review and use by ADF&G, and final data inputs and AD Model Builder code will be uploaded to the herring portion of the Ocean Workspace, together with the MS thesis of Melissa Muradian, when she defends (date set for March 2015).

**10. Response to EVOSTC Review, Recommendations and Comments:** *See*, Reporting Policy at III (C) (10).

*The Panel acknowledges the detailed and well-rounded proposal for this project. The Panel also strongly supports the recognition in the proposal that the ASA model will have a key role in synthesis. For this reason, it is essential that all participants in the upcoming synthesis meeting have a clear description of the model as currently coded. Such a description does not exist in the published literature or previous reports to EVOSTC. The description should include (i) equations; (ii) a list of parameters assigned values before model runs; and (iii) a list of parameters estimated from data and objective functions used. It does not need to include much supporting text. We suggest a target date of December 1, 2014 for this description so that attendees have ample time to take account of the model details in preparation for the synthesis meeting.*

In the Synthesis report (1 December 2014), the full specifications for the Bayesian model were provided as an Appendix 2 (Tables 2.1-2.5). Additionally, these details will be fully specified and written up in Melissa Muradian's MS thesis (defense date in March 2015), and in a scientific paper to be submitted for publication in March 2015.

*A further, more technical, comment is that there was no reason given for moving to a Bayesian framework. There are many potentially excellent reasons for this decision, but they were not presented.*

There are three main reasons for moving to a Bayesian framework: (1) automatic weighting of datasets based on the uncertainty in the data and their consistency with other data; (2) accurate and statistically valid estimates of uncertainty in biomass estimates; and (3) allows the ability to include probability in management rules for PWS herring (e.g. catches could be allowed at lower biomass if there was a low probability of small biomass).

*Is the present ASA model used for PWS identical to the model described by Hulson et al. 2008? (See Hulson, P-J. F., Miller, S. E., Quinn, T. J. II, Marty, G. D., Moffitt, S. D., and Funk, F. 2008. Data conflicts in fishery models: incorporating hydroacoustic data into the Prince William Sound Pacific herring assessment model. – ICES Journal of Marine Science, 65: 25–43.)*

The current Bayesian model does indeed build on the model by Hulson, and is very similar. Both are incorporated in AD Model Builder (Fournier et al. 2011) which allows for very fast and accurate convergence on the best estimates for model parameters. The major advance in the new model is the shift from minimizing least squares to likelihoods for each data type, and the shift from characterizing uncertainty with bootstrapping methods to the full incorporation of the model in a Bayesian framework. In combination these allow straightforward interpretation of uncertainty, and statistical weighting of different data sets.

Fournier, D.A., Skaug, H.J., Ancheta, J., Ianelli, J., Magnusson, A., Maunder, M.N., Nielsen, A., and Sibert, J. 2011. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods & Software 2011: 1-17.

*Objective 3 (Gathering data on clupeids of the world) is a formidable task, especially for a graduate student. More regional comparisons however may be useful if the analyses were confined to a smaller number, especially those in the eastern Pacific.*

The analysis in objective 3 has proceeded at pace, with the help of current work by Tim Essington, who is gathering data on small pelagic assessments for incorporation in the RAM Legacy Stock Assessment Database (www.ramlegacy.org). So far, stock assessments for 29 stocks of herring have been compiled up to 2014. Preliminary results suggest that PWS herring have been at low levels for an abnormally long period of time compared to other herring stocks. The intent is to expand this database with more stocks; gather time series of survey indices for stocks that are do not have formal stock assessments; and prepare anecdotal evidence (catches, CPUE, historical reports) for stocks that have neither stock assessments nor survey time series.

**11. Budget:** *See*, Reporting Policy at III (C) (11).

| **Budget Category:** | Proposed FY 12 | Proposed FY 13 | Proposed FY 14 | Proposed FY 15 | Proposed FY 16 | TOTAL PROPOSED | ACTUAL CUMULATIVE |
|---|---|---|---|---|---|---|---|
| Personnel | $20,734.0 | $34,445.7 | $35,823.5 | $37,256.4 | $38,746.7 | $167,006.3 | $ 86,146 |
| Travel | $982.0 | $3,636.0 | $8,194.0 | $7,812.0 | $8,508.0 | $29,132.0 | $ 10,681 |
| Contractual | $0.0 | $0.0 | $0.0 | $0.0 | $0.0 | $0.0 | $ 35,112 |
| Commodities | $200.0 | $16,884.0 | $20,552.4 | $21,286.5 | $22,050.0 | $80,972.9 | $ 1,055 |
| Equipment | $0.0 | $4,000.0 | $0.0 | $0.0 | $0.0 | $4,000.0 | $ 7,470 |
| Indirect Costs (*will vary by proposer*) | $11,944 | $20,863 | $25,188 | $25,761 | $26,952 | $110,708.0 | $ 53,446 |
| **SUBTOTAL** | $33,860.0 | $79,828.7 | $89,757.9 | $92,115.9 | $96,256.7 | $391,819.2 | $193,910.0 |
| General Administration (9% of | $3,047.4 | $7,184.6 | $8,078.2 | $8,290.4 | $8,663.1 | $35,263.7 | |
| **PROJECT TOTAL** | $36,907.4 | $87,013.3 | $97,836.1 | $100,406.4 | $104,919.8 | $427,082.9 | |
| Other Resources (Cost Share Funds) | $0.0 | $0.0 | $0.0 | $0.0 | $0.0 | $0.0 | |

COMMENTS:
This summary page provides an five-year overview of proposed funding and actual cumulative spending. The column titled 'Actual Cumulative' should be updated each fiscal year to provide information on the total amount actually spent for all completed years of the project. On the Project Annual Report Form, if any line item exceeds a 10% deviation from the originally-proposed amount; provide detail regarding the reason for the deviation.

Spending on this budget has been close to budgeted amounts for salary, tuition, and travel.

In addition to the expenses charged against the budget, in 2014-15 the current graduate student Melissa Muradian and new graduate student John Trochta have overlapped for two quarters while Muradian was finishing. In the original project it was envisaged that a single PhD student would complete the entire project. As a result, salary and tuition for Muradian came from her being a Teaching Assistant for a course Oct-Dec 2014, and she was funded as a Research Assistant on the PI's own funds Jan-March 2015. These expenses were not charged to the EVOSTC grant. It is expected that Muradian will graduate in March 2015.

***We appreciate your prompt submission and thank you for your participation.***