Dynamics of Willapa Bay, Washington
Links to the Coastal Ocean, Tidal Dispersion, and Oyster Carrying Capacity

Neil Solon Banas

A dissertation submitted in partial fulfillment
of the requirements for the degree of

Doctor of Philosophy

University of Washington
2005

Program Authorized to Offer Degree:
School of Oceanography

University of Washington
Graduate School

This is to certify that I have examined this copy of a doctoral dissertation by

Neil Solon Banas

and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Chair of Supervisory Committee:

____

Barbara M. Hickey

Reading Committee:

____

Barbara M. Hickey

____

Parker MacCready

____

Mitsuhiro Kawase

Date: ___________________________

University of Washington

Abstract

Dynamics of Willapa Bay, Washington:
Links to the Coastal Ocean, Tidal Dispersion, and Oyster Carrying Capacity

Neil Solon Banas

Chair of the Supervisory Committee:
Professor Barbara M. Hickey
School of Oceanography

Willapa Bay is a shallow, macrotidal, coastal-plain estuary where Pacific oysters (*Crassostrea gigas*) are intensively cultivated. The bay's river and ocean end members are both highly variable. Fluctuating ocean conditions—alternations between wind-driven upwelling and downwelling, and intrusions of the buoyant Columbia River plume—force huge changes in input of nutrients, phytoplankton biomass, and temperature and salt on the event (2-10 day) scale, as well as seasonally.

To infer the bay-wide salt balance from salinity time series, an effective horizontal diffusivity parameterizing all up-estuary salt flux is calculated as a function of riverflow. Results show that the overall rate of ocean-estuary exchange is relatively inflexible across seasons, buffered by strong horizontal tidal stirring, increasing only threefold from summer to winter while riverflow rises thirtyfold. A high-resolution numerical model of the bay, an implementation of GETM (General Estuarine Transport Model), is used to map this tidal exchange process in detail. A Lagrangian particle-tracking method reveals coherent lateral exchange flows interwoven with discontinuous, small-scale dispersion, as well as tidal-residual currents that in some

locations sharpen rather than smooth gradients between water masses.

Five years of chlorophyll, productivity, and nutrient measurements are used to establish that in summer, the predominant source of non-regenerated primary production in Willapa is direct import of oceanic phytoplankton blooms. Phytoplankton biomass declines up-estuary, faster than dilution by tidal dispersion could explain. Results from a version of the tidal model modified to include a non-conservative, phytoplankton-like tracer suggest that oysters and other intertidal benthic grazers may be sufficient by themselves to explain the net loss of phytoplankton within the estuary in summer. These grazers appear to be close to carrying capacity: as bay-total filtration capacity increases, the chlorophyll instrusion shortens and food intake per individual grazer declines. This occurs despite the fact that only 10-15% of the net tidal supply of oceanic phytoplankton is consumed within the estuary. Even in this well-flushed system, the small-scale structure of the tidal circulation, rather than total oceanic supply, controls overall food availability for the benthos.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PREFACE

This dissertation is adapted from four articles originally prepared for independent publication. Chapter 1 is excerpted from the summary paper by Hickey and Banas (2003). Chapter 2 is equivalent to Banas et al. (2004). Chapter 3 is the “submitted” paper by Banas and Hickey (2005). At the time of writing, Chapter 4 is an article in preparation by N.S. Banas, B.M. Hickey, J.A. Newton, and J. Ruesink. Because of these origins, there is some repetition among the Introductions in the four chapters. This repetition has been retained because the four articles are highly sequential: it is in the progressive accumulation of ideas in these Introductions that the synthesis of our physical observations, biological observations, and modeling work on Willapa Bay can be found.

ACKNOWLEDGEMENTS

The authorial “we” in the text that follows is not a royal “we” but a true “we,” a reflection of the sustained and close collaboration I enjoyed with my co-authors on the papers that became these chapters: Barbara Hickey, Parker MacCready, Jan Newton, and Jennifer Ruesink. I feel fortunate to have had Barbara to advise me throughout this work, and three others so willing to join the advising as opportunity arose.

A wider “we” opens up behind the author lists. Thanks go to Stephen Monismith, Rocky Geyer, and Alan Trimble for their conceptual contributions and for teaching me the history behind the questions at hand; to Karsten Bolding, Manuel Ruiz Villareal, Mitsuhiro Kawase, and Changshen Chen and his students for their help getting a stable, believable model of Willapa running; to our many co-investigators in the PNCERS project and the Washington SeaGrant-supported collaborations in Willapa that followed.

In Barbara Hickey’s group at the University of Washington, Bill Fredericks, Jim Johnson, and Nancy Kachel were responsible for data collection, and Sue Geier was responsible for initial data processing and quality control (as well as, day after day, keeping people, details, and deadlines from colliding painfully in more ways than I can count). At the Washington Department of Ecology, Eric Siegel, Judah Goldberg, Katherine Cox, Julia Bos, Kara van Voorhis, Casey Clishe, and Carol Maloy were responsible for data collection and processing. Many thanks go to Brett Dumbauld, Bruce Kaufman, Brian Pickering, and the Washington Department of Fish and Wildlife for their generous contribution of boat time and their own time to our cause. Thanks as well to field volunteers Adam Amundsen, Amanda Babson, Jeremy Bricker, Andy Chiodi, Jérôme Cuny, Jordan Dawe, Chris Rooper, and Tatiana Rynearson.

Finally, thanks to the many fellow students, friends, relations, and the one very significant other who supported me throughout this work in ways less scientific but even more essential.