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Title

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**California Sea Grant Sea Grant
Final Project Progress Report**

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Bacterial and Protozoal Contamination of Nearshore Marine Environments in
California, with Ecologically Sustainable Management

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Project Hypotheses

Hypothesis 1: The fecal protozoa *Cryptosporidium* will be detected more often in sentinel mussel batches located near sites considered at higher risk for human or livestock fecal pollution compared to sites considered at lower risk for exposure to these fecal sources.

Hypothesis 2: On coastal dairies, the highest loads of *Cryptosporidium* and *Giardia* will be detected in storm runoff collected near young calves, and Beneficial Management Practices (BMPs) such as vegetative buffer strips will significantly reduce the load of fecal pathogens traveling downstream in storm runoff.

Project Goals and Objectives

This project was developed to apply novel study designs and microbiology techniques to better understand and control fecal pollution flowing from terrestrial to aquatic ecosystems in California. The first objective was to evaluate the distribution of the fecal pathogen *Cryptosporidium* in nearshore waters, using mussels as bioconcentrators of the parasites from fecal contaminated waters. The second objective was to evaluate the distribution of fecal protozoa and bacteria on and around coastal farms, as well as evaluating the efficacy of a variety of Beneficial Management Practices (BMPs) in reducing the load of fecal pathogens in storm runoff on these farms. The third objective was to extend our study findings to the local and regional stakeholders, the regulatory community, and the scientific community.

Briefly describe project methodology

The project involved both laboratory and field studies to better understand the processes involved in the transport of fecal protozoa from

land to sea in stormwater runoff from coastal dairies, and how bivalves such as mussels can be used as sentinels of fecal pathogen pollution in nearshore waters.

Describe progress and accomplishments toward meeting goals and objectives

Obj. 1: Mussel testing is complete and utilized 156 batches of 30 mussels outplanted and collected quarterly over 3 years from the Tomales Bay, Monterey Bay, and Estero Bay study regions. Sites within each region were designated as higher risk for exposure to human sewage impacts, higher risk for exposure to livestock runoff, or lower risk for fecal exposure from either of these sources. Genotypes detected included *Cryptosporidium parvum*, *Cryptosporidium felis*, *Cryptosporidium andersoni*, and two novel *Cryptosporidium* spp. Factors significantly associated with detection of *Cryptosporidium* spp. in mussel batches were exposure to freshwater outflow and mussel collection within a week following a precipitation event. Detection of *Cryptosporidium* spp. was not associated with higher or lower risk status for exposure to livestock faeces or human sewage sources. This study showed that mussels can be used to monitor water quality in California and suggests that humans and animals ingesting faecal-contaminated water and shellfish may be exposed to both host-specific and anthropozoonotic *Cryptosporidium* genotypes of public health significance.

Obj. 2: Storm season sampling is complete and included over 350 water samples tested for fecal protozoa and bacteria from 13 storm events on the 5 northern California farms. Cysts were detected in 41% of runoff samples collected near cattle less than 2 months old, compared to 10% of runoff samples collected near cattle over 6 months old. Factors associated with environmental loading of *G. duodenalis* included cattle age, cattle stocking number, and precipitation but not lot area, land slope, or cattle density. Vegetated buffer strips were found to significantly reduce waterborne cysts in storm runoff while straw mulch, seed application, scraping of manure, and cattle exclusion did not. The study findings suggest that vegetated buffer strips, especially when placed near dairy calf areas, should help reduce the environmental loading of these fecal protozoa discharging from dairy farms.

Obj. 3: Stakeholders meetings were held in Morro Bay and Tomales Bay that included extension personnel, farmers, shellfish growers, California Department of Fish & Game, Central Coast Regional Water Quality Board members, and sewage plant operators. Project updates were provided to the Tomales Bay Agricultural Group, Watershed Council, and Shellfish Technical Advisory Committee. Study results have been presented at national and international meetings. The Sea Grant trainee completed her dissertation and has published 4 manuscripts based on this Sea Grant project. An extension publication was also developed to help landowners efficiently implement BMPs such as vegetative buffers in order to improve water quality.

Project modifications

No substantial modifications were needed nor problems encountered while completing this project.

Project outcomes

The project data has resulted in four peer-reviewed journal publications and one extension document that provide access to the study results and findings.

Impacts of project

This project has provided new data and insights into transport of fecal protozoa from land to sea. These findings and models are significant in the fields of ecosystem health, parasitology, epidemiology, and water quality. The journal publications, extension materials, conference presentations, and interactions with stakeholder groups have all increased the impact of these study findings and public awareness of water quality and fecal pathogen pollution issues.

Benefits, commercialization and application of project results

The sentinel mussel monitoring techniques and water testing methods have been utilized in additional research projects that build on initial Sea Grant findings. Data from the dairy BMP project is also being used to make science-based management recommendations for improving water quality on working farms.

Economic benefits generated by discovery, exploration and development of new, sustainable coastal, ocean and aquatic resources (i.e., aquaculture, marine natural products, foods, pharmaceuticals).

Economic benefits pertaining to this project are not quantifiable at this time. However, practices developed and evaluated to improve water quality on-farm will lead to reductions of impacts to water quality in Tomales Bay and therein reductions in closures to shellfish harvesting and economic impacts to aquaculture.

Issue-based forecast capabilities to predict the impacts of a single ecosystem stressor, developed and used for management (i.e., climate change, extreme natural events, pollution, invasive species, and land resource use).

Predictive modeling was used to estimate the effect that farm factors such as cattle stocking number and vegetative buffer length would have on the load of fecal protozoa in overland storm runoff on coastal dairies.

Tools, technologies and information services developed

Techniques for sentinel mussel monitoring along the California coast were developed and shared through interactions with stakeholder groups as well as in peer-reviewed publications. An extension document was developed to help landowners plan the implementation of BMPs such as vegetative buffer strips to improve water quality on dairies.

Publications

Technical reports

Title: Water Quality in the Tomales Bay Watershed: Conflict and Response to On-Farm Water Quality Management. Final Report to the Marin Community Foundation. University of California Cooperative Extension Marin County Office, Novato, California.

<http://ucce.ucdavis.edu/files/filelibrary/2161/41257.pdf>

Authors: Lewis, D.J., E. Rilla, R. Atwill, K. Tate, M. Lennox, W. Miller, L Hou, M. Pereira, D. Ghirardelli, S. Larson, and P. Olin.
Date: 2004

Conference papers, proceedings, symposia

Title: Farm factors and beneficial management practices (BMPs) associated with reducing Giardia and Cryptosporidium loading in storm runoff from dairy high use areas.

Authors: Miller, W.A., D.J. Lewis, M.D.G. Pereira, P.A. Conrad, K.W. Tate, and E.R. Atwill.

Date: 2007

Conference Title: National Conference on Ag and the Environment

Location: Monterey, California

Title: Reducing microbial contamination in runoff from concentration areas on California coastal dairies.

Authors: Lewis, D.J., E.R. Atwill, M.S. Lennox, M.D.G.C. Pereira, W.A. Miller, P.A. Conrad, J. Gustafson, and K.W. Tate.

Date: 2006

Conference Title: CSREES National Water Conference

Location: San Antonio, Texas

Title: Detection of pathogenic protozoa in marine ecosystems using mussels (*Mytilus* spp.) as bioindicators.

Authors: Miller, W.A., P. Conrad, M. Miller, I.A. Gardner, E.R. Atwill, M. Harris, J. Ames, D. Jessup, D. Paradies, K. Worcester, A. Melli, N. Barnes, P. Olin, and P.A. Conrad.

Date: 2005

Conference Title: International Wildlife Disease Association Conference

Location: Cairns, Queensland, Australia

Title: Habitat quality in California: risk factors for detecting fecal pathogens in coastal ecosystems.

Authors: Miller, W.A., E.R. Atwill, I.A. Gardner, M. Miller, M. Harris, J. Ames, D. Jessup, S. Jang, B. Byrne, A. Melli, D. Paradies, K. Worcester, P. Olin, and P. Conrad.

Date: 2005

Conference Title: International Association for Aquatic Animal Medicine

Location: Seward, Alaska

Title: Cryptosporidium epidemiology in fecal impacted coastal California ecosystems, using mussels (*Mytilus* spp.) as bioindicators.

Authors: Miller, W.A., M.A. Miller, I.A. Gardner, E.R. Atwill, M. Harris, J. Ames, D.A. Jessup, K. Worcester, D. Paradies, A.C. Melli, N.M. Barnes, P. Olin, and P.A. Conrad.

Date: 2004

Conference Title: International Giardia and Cryptosporidium Congress

Location: Amsterdam, Netherlands

Title: Cryptosporidium and Giardia: epidemiology and control on California farms.

Authors: Miller, W.A., E.R. Atwill, K.Tate, D.J. Lewis, M. Lennox, M. Pereira, and P.A. Conrad.

Date: 2003

Conference Title: World Association for the Advancement of Veterinary Parasitology
Location: New Orleans, Louisiana

Title: Surface Water Fecal Coliform Load Within Coastal Dairy Watersheds.
Authors: Lewis, D.J. K.W. Tate, and E.R. Atwill.
Date: 2003

Conference Title: CSREES Pacific Northwest Regional Water Quality Program - Getting It Done: The Role of TMDL Implementation in Watershed Restoration
Location: Stevenson, Washington

Title: Cryptosporidium epidemiology in fecal impacted coastal California ecosystems, using mussels (*Mytilus* spp.) as bioindicators.
Authors: Miller, W.A., M.A. Miller, I.A. Gardner, E.R. Atwill, M. Harris, J. Ames, D.A. Jessup, K. Worcester, D. Paradies, A.C. Melli, N.M. Barnes, P. Olin, and P.A. Conrad.
Date: 2004

Conference Title: International Giardia and Cryptosporidium Congress
Location: Amsterdam, Netherlands

Title: Cryptosporidium and Giardia: epidemiology and control on California farms.
Authors: Miller, W.A., E.R. Atwill, K.Tate, D.J. Lewis, M. Lennox, M. Pereira, and P.A. Conrad.
Date: 2003

Conference Title: World Association for the Advancement of Veterinary Parasitology
Location: New Orleans, Louisiana

Title: Making Water Quality Management Decisions on Dairies in the Tomales Bay Watershed.
Authors: Lewis, D.J., N. Scolari, N. King, and D. Hopkins. 2003.
Date: 2003

Conference Title: Restoring Clean Water: Nonpoint Source Pollution Prevention and TMDLs. Biosketches and Abstracts for the California 2003 Nonpoint Source(NPS) Conference.
Location: Santa Barbara, California

Title: Evidence of pathogen pollution: shellfish as bioindicators of fecal-borne pathogenic protozoa and bacteria in theCalifornia nearshore marine ecosystem.
Authors: Smith, W.A., M.A. Miller, I.A. Gardner, C.M. Leutenegger, S. Jang, E.R. Atwill, P.A. Conrad.
Date: 2002

Conference Title: Wildlife Disease Association Annual Conference
Location: Humboldt, California

Title: Systems approach for management of fecal coliform loading in a coastal watershed.
Authors: Lewis, D.J., M. Lennox, K.W. Tate, E.R. Atwill, E. Rilla, S. Larson.
Date: 2001

Conference Title: American Water Resources Association Annual Water Resources Conference

Location: Albuquerque, New Mexico

Title: Protozoal problems emerging at the human-wildlife-domestic animal interface.

Authors: Conrad, P.A., M.A. Miller, A. Kjemturp, I.A. gardner, C. Kreuder, W.A. Smith, E.R. Atwill.

Date: 2002

Conference Title: Wildlife Disease Association Annual Meeting

Location: Humboldt, California

Peer-reviewed journal articles or book chapters

Title: Evaluation of methods for improved detection of *Cryptosporidium* spp. in mussels (*Mytilus californianus*).

Authors: Miller, W.A., I.A. Gardner, C.M. Leutenegger, M. Miller, E.R. Atwill, R. Hedrick, A.C. Melli, N. Barnes, and P.A. Conrad.

Date: 2005

Journal Name: Journal of Microbiological Methods

Issue/Page Numbers: 65: 367-379

Title: New genotypes and factors associated with *Cryptosporidium* detection in mussels (*Mytilus* spp.) along the California coast.

Authors: Miller, W.A., M.A. Miller, I.A. Gardner, E.R. Atwill, A.C. Melli, M. Harris, J. Ames, K. Worcester, N. Barnes, D. Jessup, and P.A. Conrad.

Date: 2005

Journal Name: International Journal for Parasitology

Issue/Page Numbers: 35:1103-1113

Title: Climate and on-farm risk factors associated with *Giardia duodenalis* cysts in storm runoff from California coastal dairies.

Authors: Miller, W.A., D.J. Lewis, M. Lennox, M.D.G.C. Pereira, K.W. Tate, P.A. Conrad, and E.R. Atwill.

Date: 2007

Journal Name: Applied and Environmental Microbiology

Issue/Page Numbers: 73:6972-6979

Title: Water Quality Treatment for Livestock Feeding and Exercise Areas on California Coastal Dairy Farms and Ranches.

Authors: Lennox, M.S., D.J.Lewis, J. Gustafson, K.W. Tate, and E.R. Atwill.

Year 2007

Journal: University of California Division of Agriculture and Natural Resources. Publication 8210.

Title: Farm factors associated with reducing *Cryptosporidium* loading in storm runoff from dairy high use areas.

Authors: Miller, W.A., D.J.L. Lewis, M. Lennox, M.D.G. Pereira, P.A. Conrad, K.W. Tate, and E.R. Atwill.

Date: 2008

Journal Name: Journal of Environmental Quality

Issue/Page Numbers: In Press

Electronic publications

Title: Farm and Ranch Stewardship.

http://cesonoma.ucdavis.edu/Watershed_Management923/Farm_&_Ranch_Stewardship.htm

Authors: Lewis, D.J., S. Nossaman, and M.S. Lennox.
Date: 2007

Title: Management options to reduce microbial, nutrient, and sediment pollutants in runoff from grazed, irrigated pastures. (Approved and in production).

Authors: Tate, K.W., D.F. Lile, M. Doran, T. Beccheti, R. Atwill, and D. Lewis.

Date: 2008.

Publisher: Division of Agriculture and Natural Resources Communication Services.

Theses, dissertations

Title: Cryptosporidium species in coastal California ecosystems

Authors: Miller, W.A.

Schools: University of California, Davis

Date: 12/2004

Newsletters, periodicals

Title: Strategies to prevent winter erosion at dairies.

Authors: Gale, I., M. Lennox and D. Lewis.

Date: 2007

Newsletter: Marin Resource Conservation District

Title: Ranchers protect water quality.

Authors: Gale, I., D. Lewis, and N. Scolari.

Date: 2005.

Newsletter: Marin Resource Conservation District

Title: All streams lead to Tomales bay.

Authors: Quirt, S. and D. Lewis

Date: 2004

Newsletter: UCCE Grown in Marin.

Media

Public Radio International Living on Earth

City: Somerville

State: Massachusetts

Date of publication/broadcast: 08/18/06

Headline or topic: Middle ground - Collaboration and compromise to improve environmental conditions and local food production in the Tomales Bay Watershed.

Point Reyes Light

City: Point Reyes Station

State: California

Date of publication/broadcast: 07/10/03

Headline or topic: Finding what's causing Bay pollution.

KRON Television Channel 4

City: San Francisco

State: California

Date of publication/broadcast: 5/15/03

Headline or topic: Tomales Bay water quality

Please list any workshops/presentations given

Title: Chip to Creek to Estuary

Audience Type: Board of Directors for Marin Resource Conservation District

Location: Point Reyes Station, California

Date: 06/13/07

Number Attending: 13

Content: Fate and transport of microbial pollution in livestock agriculture including the role of BMPs to improve water quality.

Title: Cut the Crap

Audience Type: Livestock producers, resource and regulatory agency staff

Location: Santa Barbara, California

Date: 1/30 and 31/07

Number Attending: 110

Content: Understanding of livestock agriculture's role in microbial pollution and solutions for reducing any impacts to surface water quality.

Title: Chip to creek to estuary

Audience Type: Resource and regulatory agency staff and livestock producers

Location: Point Reyes Station, California

Date: 01/17/07

Number of attendees: 27

Content: Fate and transport of microbial pollution in livestock agriculture including the role of BMPs to improve water quality.

Title: Roles and benefits of conservation practices to improve stream habitat and water quality

Audience Type: Grazing livestock and dairy producers

Location: Middle Two Rock, California

Date: 12/07/06

Number of attendees: 31

Content: Results from research on the effectiveness of on-farm practices to reduce fecal coliform concentration and loading

Title: Being a successful water quality steward.

Audience Type: Ranchers, dairy producers, and resource management professionals

Location: Point Reyes Station, Ferndale, and Crescent City, California

Date: 10/19, 25, and 26/05

Number of attendees: 56

Content: Fate and transport of microbial pollution in livestock agriculture and methods to reduce surface water quality impacts.

Title: Water quality management on dairies.

Audience type: Dairy producers

Location: Middle Two Rock, California

Date: 11/04/04

Number attending: 17

Content: Benefits of conservation practices to reduce surface water impacts.

Title: Water quality management on dairies

Audience Type: Dairy producers

Location: Middle Two Rock, California

Date: 04/08/04

Number attending: 15

Content: Fate and transport of microbial pollution in livestock agriculture and methods to reduce surface water quality impacts.

Title: Town hall meeting for bacteria and water quality: Agency and organization efforts to manage and regulate bacterial water quality in Tomales Bay Watershed.

Audience Type: Ranchers, community members, and agency representatives

Location: Point Reyes Station, California

Date: 03/10/04

Number of attendees: 107

Content: Description of agency and organizations policies, procedures, and initiatives to improve water quality in the Tomales Bay Watershed.

Dissemination of results

Project concepts and findings are being made available on both our ranch stewardship and pathogen pollution website:

cesonoma.ucdavis.edu/Watershed_Management923/Farm_&_Ranch_Stewardship.htm;

and

www.pathogenpollution.org

Students

Woutrina A. Miller

University of California, Davis

Vet Med: Pathology, Microbiology & Immunology

Degree program enrolled in: Ph.D.

Theses/dissertation title: Cryptosporidium species in coastal California ecosystems

Supported by Sea Grant funds? yes

Start date: 3/01/2002

End date: 12/31/2004

Cooperating organizations

Local and state

University of California Cooperative Extension - As a full project co-leader, provided intellectual input, participated in project implementation, and interfaced with stakeholder groups.

University of California Center for Food Animal Health - provided additional support for the project.

California Department of Fish & Game - provided expertise, equipment, and personnel for the project.

Central Coast Regional Water Quality Control Board - provided guidance and agency perspective for water quality issues.

Tomales Bay Agricultural Producers Group - provided a forum for discussion of the project concept and findings before and during implementation.

Bay Foundation of Morro Bay - provided intellectual input and a forum for discussion of project design and findings with stakeholder groups.

California Mussel Watch Program - provided expertise and assistance with project implementation.

Bodega Marine Laboratory - provided project support and expertise.

Granite Canyon Marine Laboratory - provided facilities and project support.

International implications

The lessons learned during this project may apply to farms and coastal areas worldwide, as pathogen pollution flowing from terrestrial to aquatic ecosystems is now recognized in many countries. The results and recommendations from our study with regard to implementing Beneficial Management Practices to reduce fecal pollution in overland runoff and utilizing bivalve shellfish as bioindicators of fecal pollution in aquatic ecosystems can be applied elsewhere to better understand and control fecal pollution using practical and sustainable methods.

Awards

Conrad, P.A.: 1. Oscar W. Schalm Lectureship, School of Veterinary Medicine, University of California, Davis, California, 2003; 2. Aldo Leopold Leadership Program Fellow, Connecticut and Washington DC, 2004.

Keywords

Bacteria, coliform, protozoa, cryptosporidium, giardia, water quality, shellfish, bivalve, mussel, farm, livestock, cattle, dairy, fecal pollution, beneficial management practices, BMP, storm runoff, pathogen pollution.

Notes

The work completed through this project and with California Sea Grant's support has and continues to have direct relevance for the Bay Pathogen TMDL and subsequent Conditional Waiver for Grazing Lands in the Tomales Bay Watershed. The research and outreach efforts have provided direction to both the regulated and regulatory communities on how to address water quality impacts from livestock agriculture in a more focused and efficient manner.