Annual Report for Period: 12/2008 - 11/2009
Submitted on: 09/01/2009
Principal Investigator: Reed, Daniel C.
Award ID: 0620276
Organization: U of Cal Santa Barbara
Submitted By:
Reed, Daniel - Principal Investigator
Title:
LTER: Land/Ocean Interactions and the Dynamics of Kelp Forest Communities

Project Participants

Senior Personnel

Name: Reed, Daniel
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Melack, John
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Holbrook, Sally
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Gaines, Steven
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Siegel, David
Worked for more than 160 Hours: Yes
Contribution to Project:

Name: Dugan, Jenny
Worked for more than 160 Hours: Yes
Contribution to Project:
Project coordinator and sandy beach research

Name: Whitmer, Allison
Worked for more than 160 Hours: Yes
Contribution to Project:
Directs on campus marine outreach and education activities

Name: Page, Henry
Worked for more than 160 Hours: Yes
Contribution to Project:
Reef ecology research including stable isotope analyses

Name: Washburn, Libe
Worked for more than 160 Hours: Yes
Contribution to Project:
Oceanographic research

Name: Brzezinski, Mark

Worked for more than 160 Hours: Yes
Contribution to Project:
Coastal Oceanography research

Name: Cooper, Scott
Worked for more than 160 Hours: No
Contribution to Project:
Stream ecology research

Name: Carlson, Craig
Worked for more than 160 Hours: Yes
Contribution to Project:
Marine microbial ecology

Name: Cardinale, Brad
Worked for more than 160 Hours: Yes
Contribution to Project:
Long term experiments and synthesis

Name: Guerrini, Anita
Worked for more than 160 Hours: Yes
Contribution to Project:
Historical research on coastal watersheds

Name: Zimmerman, Richard
Worked for more than 160 Hours: No
Contribution to Project:
Algal physiology and ecology research

Name: Schmitt, Russell
Worked for more than 160 Hours: Yes
Contribution to Project:
kelp forest community ecology

Name: Schimel, Joshua
Worked for more than 160 Hours: Yes
Contribution to Project:
Watershed nutrient research

Name: Nisbet, Roger
Worked for more than 160 Hours: Yes
Contribution to Project:
Ecological modeling

Name: McPhee-Shaw, Erika
Worked for more than 160 Hours: Yes
Contribution to Project:
Coastal oceanographic research

Name: MacIntyre, Sally
Worked for more than 160 Hours: Yes
Contribution to Project:
Limnologic and oceanographic research

Name: Even, Thomas
Worked for more than 160 Hours: No
Contribution to Project:

Stream ecology

Name: Gaylord, Brian
Worked for more than 160 Hours: Yes
Contribution to Project:
Kelp forest hydrodynamics and biomechanics

Name: Lenihan, Hunter
Worked for more than 160 Hours: Yes
Contribution to Project:
Reef ecology and fisheries

Name: Carr, David
Worked for more than 160 Hours: Yes
Contribution to Project:
Reef fisheries research

Name: Dudley, Tom
Worked for more than 160 Hours: No
Contribution to Project:
watershed and invasive plant research

Name: Beighley, Ed
Worked for more than 160 Hours: Yes
Contribution to Project:
Watershed hydrology

Name: Freudenburg, William
Worked for more than 160 Hours: No
Contribution to Project:
Sociological studies

Name: Clarke, Keith
Worked for more than 160 Hours: No
Contribution to Project:
Land use research

Name: Holden, Patricia
Worked for more than 160 Hours: Yes
Contribution to Project:
Microbial Ecology including bacterial and water quality research in coastal watersheds

Name: Tague, Christina
Worked for more than 160 Hours: No
Contribution to Project:
Research and modeling on how eco-hydrologic systems are altered by changes in land use and climate

Name: Smith, Chris
Worked for more than 160 Hours: No
Contribution to Project:
Assist in collecting stream chemistry samples during storms

Name: Bennett, Danuta
Worked for more than 160 Hours: Yes
Contribution to Project:
Algal sampling and identification for stream samples

Name: Nelson, Craig

Worked for more than 160 Hours: No

Contribution to Project:

Physical-chemical measurements and bacterial analyses

Post-doc

Name: Miller, Robert

Worked for more than 160 Hours: Yes

Contribution to Project:

Develop apparatus and experiments investigating primary production of understory algae and phytoplankton in kelp forests

Name: Fram, Jonathan

Worked for more than 160 Hours: Yes

Contribution to Project:

Analysis of current, temperature, nutrient data for kelp forest and nearshore ocean

Name: Stewart, Hannah

Worked for more than 160 Hours: Yes

Contribution to Project:

Researched kelp forest dynamics in response to nutrient flow

Name: Revell, David

Worked for more than 160 Hours: No

Contribution to Project:

Sediment and sandshed dynamics of coastal beaches

Name: Miterai, Satoshi

Worked for more than 160 Hours: Yes

Contribution to Project:

ROMS modeling of larval connectivity with headlands

Name: Alberto, Filipe

Worked for more than 160 Hours: No

Contribution to Project:

Population genetics of kelps

Name: He, Yiping

Worked for more than 160 Hours: Yes

Contribution to Project:

watershed hydrology research

Name: Leydecker, Al

Worked for more than 160 Hours: Yes

Contribution to Project:

Watershed sampling and analyses

Name: Fewings, Melanie

Worked for more than 160 Hours: Yes

Contribution to Project:

Physical Oceanography

Name: Byrnes, Jarrett

Worked for more than 160 Hours: Yes

Contribution to Project:

Research on disturbance and community structure of benthic communities

Graduate Student

Name: Arkema, Katie
Worked for more than 160 Hours: Yes
Contribution to Project:
Kelp forest community ecology, kelp primary production

Name: Rassweiler, Andrew
Worked for more than 160 Hours: Yes
Contribution to Project:
Kelp forest community ecology, kelp primary production

Name: Carney, Laura
Worked for more than 160 Hours: Yes
Contribution to Project:
kelp population genetics research

Name: Nickols, Kerry
Worked for more than 160 Hours: Yes
Contribution to Project:
kelp biomechanics research

Name: Hettinger, Anniliese
Worked for more than 160 Hours: Yes
Contribution to Project:
kelp biomechanics research

Name: Guenther, Carla
Worked for more than 160 Hours: Yes
Contribution to Project:
Fishery socioeconomics and management in kelp forests

Name: Harrer, Shannon
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with reef and oceanographic research and data management

Name: Simon, Scott
Worked for more than 160 Hours: Yes
Contribution to Project:
Coordinates on campus marine outreach and education activities

Name: Hammond, Latisha
Worked for more than 160 Hours: Yes
Contribution to Project:
Assists with on-campus marine outreach and education

Name: Klose, Kristie
Worked for more than 160 Hours: Yes
Contribution to Project:
Stream ecology research

Name: Shulman, Rachel
Worked for more than 160 Hours: Yes
Contribution to Project:
Long term experiments and synthesis

Name: Burnette, Don

Worked for more than 160 Hours: No

Contribution to Project:
History of botanical research on a coastal watershed

Name: Cavanaugh, Kyle

Worked for more than 160 Hours: Yes

Contribution to Project:
SPOT analysis of kelp cover/biomass

Name: Watson, James

Worked for more than 160 Hours: Yes

Contribution to Project:
modeling of larval & genetic connectivity for SBC-LTER

Name: Chaffey, Tim

Worked for more than 160 Hours: Yes

Contribution to Project:
ROMS modeling of larval connectivity with headlands

Name: Kostadinov, Tiho

Worked for more than 160 Hours: Yes

Contribution to Project:
coastal oceanographic research

Name: Anderson, Clarissa

Worked for more than 160 Hours: Yes

Contribution to Project:
coastal oceanographic research

Name: Wallner, Elisa

Worked for more than 160 Hours: Yes

Contribution to Project:
coastal oceanographic research

Name: Goldberg, Stuart

Worked for more than 160 Hours: Yes

Contribution to Project:
coastal oceanographic research

Name: Goodman, Jo

Worked for more than 160 Hours: Yes

Contribution to Project:
coastal oceanographic research

Name: Levenbach, Stuart

Worked for more than 160 Hours: Yes

Contribution to Project:
Kelp forest community ecology

Name: Lester, Sarah

Worked for more than 160 Hours: No

Contribution to Project:
Kelp forests and population biology of urchins

Name: Brinkman, Jeff

Worked for more than 160 Hours: No

Contribution to Project:

Stream ecology

Name: Kinlan, Brian
Worked for more than 160 Hours: Yes
Contribution to Project:
ecology of kelp forests

Name: Kargar, Maryann
Worked for more than 160 Hours: Yes
Contribution to Project:
watershed hydrology research

Name: Bogonko, Michael
Worked for more than 160 Hours: Yes
Contribution to Project:
watershed hydrology research

Name: Shields, Catherine
Worked for more than 160 Hours: Yes
Contribution to Project:
Watershed research and modeling

Name: Smyth, Robyn
Worked for more than 160 Hours: Yes
Contribution to Project:
Research on biogeochemical responses to physical processes in the coastal ocean.

Name: Finger, Helene
Worked for more than 160 Hours: Yes
Contribution to Project:
Research on biogeochemical responses to physical processes in the coastal ocean.

Name: Landgren, Kristin
Worked for more than 160 Hours: Yes
Contribution to Project:
Research on coastal ocean productivity

Name: Goodman, Darcie
Worked for more than 160 Hours: Yes
Contribution to Project:
Research on coastal watersheds and estuaries

Name: Melton, Christopher
Worked for more than 160 Hours: Yes
Contribution to Project:
Research on coastal ocean productivity and conditions

Name: Sadro, Steve
Worked for more than 160 Hours: No
Contribution to Project:
Physical-chemical measurements and analyses of stream samples.

Name: Cano, Aubrey
Worked for more than 160 Hours: No
Contribution to Project:
Assisted in K-12 program coordination and execution (Schoolyard?Floating Lab Component, MSP?teacher PD)

Name: Rathbone, Sarah

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?Floating Lab Component, MPS?Teacher professional development).

Name: Rodriguez, Gabe

Worked for more than 160 Hours: Yes

Contribution to Project:
Kelp forest research

Name: Dellaripa, Nicholas

Worked for more than 160 Hours: Yes

Contribution to Project:
Working on SBC-LTER cruise data and other regional oceanographic data set

Undergraduate Student

Name: Jolley, Margaret

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research, data and lab sample processing

Name: Horii, Stephanie

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research, data and lab sample processing

Name: Rompel, Jenna

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research, data and lab sample processing

Name: Creason, Jamie

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research and lab sample processing

Name: Kondo, Emi

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research and lab sample processing

Name: Zimmer-Faust, Amy

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research and lab sample processing

Name: James, Kelsey

Worked for more than 160 Hours: No

Contribution to Project:
Assists with on-campus marine outreach and education

Name: Le, Kevin

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with subtidal kelp forest research and lab sample processing

Name: Finstad, Sarah
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with subtidal kelp forest research and lab sample processing

Name: Santschi, Christen
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with subtidal kelp forest research and lab sample processing

Name: Quigley, Yasmin
Worked for more than 160 Hours: No
Contribution to Project:
Assists with on-campus marine outreach and education

Name: Naranjo, Vanessa
Worked for more than 160 Hours: No
Contribution to Project:
Assists with on-campus marine outreach and education

Name: Olsen, Lani
Worked for more than 160 Hours: No
Contribution to Project:
process stream samples, filter water samples for particulates, measure conductivity on stream samples

Name: Teeza, Inteema
Worked for more than 160 Hours: No
Contribution to Project:
process stream samples, filter water samples for particulates, measure conductivity on stream samples

Name: Minter, Thomas
Worked for more than 160 Hours: No
Contribution to Project:
Sample collection from streams during storm events

Name: Padilla, Emmanuel
Worked for more than 160 Hours: No
Contribution to Project:
Sample collection from streams during storm events

Name: Bowen, Kevin
Worked for more than 160 Hours: Yes
Contribution to Project:
Performed nutrient analyses and data entry in laboratory for watershed, stream and beach samples, performed some quality control analyses.

Name: Moon, Evan
Worked for more than 160 Hours: Yes
Contribution to Project:
assisting in SPOT data analysis

Name: Fairbarn, Kenneth
Worked for more than 160 Hours: Yes
Contribution to Project:
assisting in SPOT data analysis

Name: Nielsen, Jessica

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Cady, Samantha

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Madras, Marie

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Silbert, Matthew

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: You, Jiayang

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with information management, database construction and web applications

Name: Griffiths, Marc

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Allman, Erin

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Miller, Kate

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Jew, Gregory

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Most, Mackenzie

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Hazen, Michael

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Barkley, Yvonne

Worked for more than 160 Hours: No

Contribution to Project:

Assisted with kelp forest research and lab sample processing

Name: Artis, Austin
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Linard, Erica
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Dilley, Eric
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Schwarzkopf, Zacary
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Lever, Jeremie
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Chanco, Michael
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Edwards, Kristen
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Gower, Yvonne
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Judge, Jenna
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Gherardi, Kristyn
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Karm, Debi
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Swann, Justine

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: McAlexander, Laurie

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Phares, Natalie

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Stroud, Ashley

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Novoa, Anai

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Flores, Jonathan

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Borchart, Sinaed

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Boccio, Gina

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Nicholson, Lisa

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Gibson, Carolyn

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with kelp forest research and lab sample processing

Name: Yu, Gordon

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with maintenance of the SBC-LTER real-time data display system on Stearns Wharf.

Name: Villanueva, Karie

Worked for more than 160 Hours: No

Contribution to Project:

Processed stream water and sediment samples

Name: West, Laura
Worked for more than 160 Hours: No
Contribution to Project:
Processed stream water and sediment samples

Name: Gonter, Lauren
Worked for more than 160 Hours: No
Contribution to Project:
Processed stream water and sediment samples

Name: Svete, Lindsey
Worked for more than 160 Hours: No
Contribution to Project:
Collected stream chemistry samples during storms. Processed stream water and sediment samples

Name: Journales, Mary
Worked for more than 160 Hours: No
Contribution to Project:
Processed stream water and sediment samples

Name: Paine, Christina
Worked for more than 160 Hours: No
Contribution to Project:
Processed stream water and sediment samples

Name: Flavin, Kimberly
Worked for more than 160 Hours: No
Contribution to Project:
Processed stream water and sediment samples

Name: Buffington, Gary
Worked for more than 160 Hours: No
Contribution to Project:
Assist in collecting stream chemistry samples during storms

Name: Lipps, Megan
Worked for more than 160 Hours: No
Contribution to Project:
Assist in collecting stream chemistry samples during storms

Name: Gluchowski, David
Worked for more than 160 Hours: No
Contribution to Project:
Assist in collecting stream chemistry samples during storms

Name: Rosser, Nathan
Worked for more than 160 Hours: No
Contribution to Project:
Assist in collecting stream chemistry samples during storms

Name: Patton, Judd
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with laboratory and field research on streams

Name: Hurtado, Vivian

Worked for more than 160 Hours: No

Contribution to Project:
Assisted with laboratory and field research on streams

Name: Baxter, Catherine

Worked for more than 160 Hours: Yes

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Rink, Laura

Worked for more than 160 Hours: Yes

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Aguanno, Kristen

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Allmann, Erin

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Beckler, Michael

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Bonsell, Christina

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Choy, Robynn

Worked for more than 160 Hours: Yes

Contribution to Project:
Assisted with kelp forest research, data, and lab processing
Assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Cowen, Jane

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Fong, Carrie

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Frietas, Elyse

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Keller, Kaely

Worked for more than 160 Hours: No

Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Lam, Laurel
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with subtidal kelp forest research, data, and lab processing
Assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: McFarlin, Michael
Worked for more than 160 Hours: No
Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Ophanon, Justine
Worked for more than 160 Hours: No
Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Schorrock, Kait
Worked for more than 160 Hours: No
Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Stolzenbach, Kevin
Worked for more than 160 Hours: No
Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Xue, Yun Feng
Worked for more than 160 Hours: No
Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum and Floating Lab)

Name: Logan, Rebekah
Worked for more than 160 Hours: No
Contribution to Project:
assisted in K-12 program coordination and execution (Schoolyard?SBC-LTER curriculum)

Name: Anton, Cassidy
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Amenta, Allison
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Collins, Haley
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Foster, Matt
Worked for more than 160 Hours: Yes
Contribution to Project:

Assisted with kelp forest research, data, and lab processing

Name: Heindel, Sara
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Lin, Mike
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Nadal, Ana
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Ramos, Kim
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Shen, Erika
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Torres, Stephanie
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with kelp forest research, data, and lab processing

Name: Kirkey, Matthew
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with field and laboratory studies of sandy beaches

Name: Barrows, Mercer
Worked for more than 160 Hours: Yes
Contribution to Project:
assists with SBC-LTER field work and has been working on calibration of newly developed pressure sensors for use in the SBC-LTER

Name: Langenback, Tony
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with processing invertebrate samples from SBC reefs

Name: Kahn, Alena
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with processing invertebrate samples from SBC reefs

Name: Iwanicki, Suzanne
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with processing invertebrate samples from SBC reefs

Name: Fox, Beth
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with processing invertebrate samples from SBC reefs

Name: Rich, Andrew
Worked for more than 160 Hours: No
Contribution to Project:
Assisted with processing invertebrate samples from SBC reefs

Technician, Programmer

Name: Nelson, Clint
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with reef and oceanographic research and data management

Name: Fisher, Rachelle
Worked for more than 160 Hours: Yes
Contribution to Project:
Assisted with reef and oceanographic research and data management

Name: Goodridge, Blair
Worked for more than 160 Hours: Yes
Contribution to Project:
: Assisted with reef, oceanographic and watershed research

Name: Kissinger, Michelle
Worked for more than 160 Hours: No
Contribution to Project:
Assists with on-campus marine outreach and education

Name: Nakase, Dana
Worked for more than 160 Hours: No
Contribution to Project:
Assists with on-campus marine outreach and education

Name: O'Brien, Margaret
Worked for more than 160 Hours: Yes
Contribution to Project:
IM coordinator

Name: Schooler, Nicolas
Worked for more than 160 Hours: Yes
Contribution to Project:
Assists with reef and sandy beach research

Name: Setaro, Frank
Worked for more than 160 Hours: Yes
Contribution to Project:
Processing stream and watershed samples in laboratory

Name: Doyle, Allen
Worked for more than 160 Hours: Yes
Contribution to Project:

Analytical lab manager, performed and coordinated nutrient analyses for freshwater inorganic and total nutrients. Logged samples, created spreadsheets, performed quality analysis

Name: Fields, Erik
Worked for more than 160 Hours: Yes
Contribution to Project:
satellite image data processing

Name: Jones, Janice
Worked for more than 160 Hours: Yes
Contribution to Project:
coastal oceanographic research

Name: Gotschalk, Chris
Worked for more than 160 Hours: Yes
Contribution to Project:
coastal oceanographic research and data processing

Name: Court, David
Worked for more than 160 Hours: No
Contribution to Project:
remote sensing data analyses

Name: Emery, Brian
Worked for more than 160 Hours: Yes
Contribution to Project:
ocean surface currents research

Name: Ireson, Kirk
Worked for more than 160 Hours: Yes
Contribution to Project:
ocean surface currents research

Name: Guillocheau, Nathalie
Worked for more than 160 Hours: Yes
Contribution to Project:
Plumes and Blooms research

Name: Wiseman, Sheila
Worked for more than 160 Hours: No
Contribution to Project:
Stream ecology

Name: Morris, Jordan
Worked for more than 160 Hours: Yes
Contribution to Project:
server and database management

Name: Burt, Chad
Worked for more than 160 Hours: Yes
Contribution to Project:
information management

Name: Meyerhof, Matthew
Worked for more than 160 Hours: Yes
Contribution to Project:
Coordinated undergrads for storm sampling, conducted both storm and baseflow chemistry sampling, and assisted us with our

chemistry data analysis and processing

Name: Donahue, Christine

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with reef and oceanographic research

Name: Moy, Shannon

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with historical sandy beach data and imagery and field studies

Other Participant

Name: Ralph, Yvette

Worked for more than 160 Hours: No

Contribution to Project:

Assisted with subtidal kelp forest research

Name: Reifel, Stanley

Worked for more than 160 Hours: Yes

Contribution to Project:

Developed the circuit board now being used in the new wave-measuring pressure sensors developed for the SBC-LTER.

Name: Johnson, Cyril

Worked for more than 160 Hours: No

Contribution to Project:

Helped design and who fabricated the new wave-measuring pressure sensors developed for the SBC-LTER

Research Experience for Undergraduates

Name: Davenport, Lars

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with subtidal kelp forest research

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree

Fiscal year(s) REU Participant supported: 2007

REU Funding: REU supplement

Name: Craig, Alexandra

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with subtidal kelp forest research

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree

Fiscal year(s) REU Participant supported: 2007

REU Funding: REU supplement

Name: Heidelberger, Sara

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with subtidal kelp forest sampling and lab sample processing

Years of schooling completed: Sophomore

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree

Fiscal year(s) REU Participant supported: 2007

REU Funding: REU supplement

Name: Cody, Tim

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with subtidal kelp forest sampling and lab sample processing

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree

Fiscal year(s) REU Participant supported:

REU Funding: REU supplement

Name: Honig, Susanna

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with subtidal kelp forest research and lab sample processing

Years of schooling completed: Sophomore

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree

Fiscal year(s) REU Participant supported: 2007

REU Funding: REU supplement

Name: Christie, Jocelyn

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with kelp forest research, data and lab sample processing

Name: Nolan, Ryan

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with information management, database construction and web applications

Years of schooling completed: Junior

Home Institution: Same as Research Site

Home Institution if Other:

Home Institution Highest Degree Granted(in fields supported by NSF): Bachelor's Degree

Fiscal year(s) REU Participant supported: 2009

REU Funding: REU supplement

Name: Henry, Rachel

Worked for more than 160 Hours: Yes

Contribution to Project:

Assisted with kelp forest research, data, and lab processing

Years of schooling completed: Junior
Home Institution: Same as Research Site
Home Institution if Other:
Home Institution Highest Degree Granted(in fields supported by NSF): Doctoral Degree
Fiscal year(s) REU Participant supported: 2009
REU Funding: No Info

Organizational Partners

NOAA National Marine Sanctuary Program

A major goal of the Channel Islands National Marine Sanctuary (http://www.cinms.nos.noaa.gov/home.htm)is to direct research and monitoring programs that will yield a body of information that can be used to evaluate existing management practices and provide improved understanding for future management decisions. CINMS has provided ship time and staff expertise to UCSB's Plumes and Blooms project and has offered similar support to the SBC LTER. CINMS has been an enthusiastic supporter of SBC because information generated by SBC will assist them in their efforts to manage and protect the Sanctuary. CINMS is currently considering expanding its boundaries to include much of the mainland coast in the Santa Barbara Channel and has been active in state-wide efforts to establish marine reserves. Both of these activities could greatly influence the level of protection afforded to marine habitats in the SBC LTER. Six SBC investigators served on a science advisory panel to CINMS to develop a plan to create a network of marine protected areas in the sanctuary and state waters.

Santa Barbara Land Trust

The Santa Barbara Land Trust has purchased the lower half of the Arroyo Hondo catchment, a parcel owned for generations by a couple of families and only slightly altered; the upper portion is administered by the US Forest Service as natural watershed. As part of a Bren School's Masters of Environmental Science and Management thesis project, we developed a natural resources management plan for the Land Trust. Further, the catchment is one of our intensive sites, and we will continue to provide useful information to the Land Trust as they protect and manage the property.

University of California, Davis, CA

Old Dominion University

Research collaborations on studies of kelp primary production

Los Angeles Conservation Corps

Collaborators on SBC-LTER's schoolyard program for K-12 education

Santa Barbara Channel Keeper

The Santa ChannelKeepers conduct monthly collections along the Ventura River, and we participate in this field work and complement their in situ measurements with high quality nutrient chemistry.

Ventura CoastKeeper

Provides stream sampling volunteers and sample collections for watershed research.

Carpinteria Creek Watershed Coalition

Univ. California Natural Reserve System

Friends of the Santa Clara River

City of Santa Barbara

The City of Santa Barbara recently obtained special funding through a voter approved tax increase to reduce polluted runoff that has resulted in beach closures. Two of our intensively studied catchments (Mission and Arroyo Burro) are within the City, and we are interacting with city staff to help plan their restoration efforts.

Santa Barbara County Project Clean Water

Santa Barbara County's Project Clean Water in engaged in sampling local creeks during the initial rise of the hydrograph and measuring a suite of pollutants including metals, pesticides and herbicides. Our intensive sampling of nutrients and particulates during the whole hydrograph for most storms complements the County's effort, and we and they share data and interpretations. To further communication with Project Clean Water, we attend their monthly stakeholder meetings and have given public presentations of our results in that forum.

Channel Islands National Park

Since 1982 Channel Islands National Park (http://www.nps.gov/chis/) has collected data annually on the abundance of a wide variety of species that inhabit intertidal reefs and kelp forests at a multitude of sites on the five northern Channel Islands (http://www.nature.nps.gov/im/chis/index.htm). These data have proved extremely valuable in evaluating the response of nearshore reef communities to large disturbances (e.g. El Nino) that have occurred in the last 20 years. SBC has adopted sampling protocols similar to those used by NPS to examine long-term changes in reef populations on the mainland. When used in combination, NPS and SBC data provide large spatial resolution for evaluating changes in reef communities that occur in the future. This collaboration is important because it provides NPS with important information on the physical and biological oceaography of the Santa Barbara Channel, which otherwise would not be available to them. This information is useful in helping NPS manage and protect the unique and valuable resources of the Channel Islands.

Terra Image USA

Center for Integrative Coastal Observ.

La Cumbre Junior High School

The mission of LCJHS is to promote and support academic excellence and the well-being of each student; to promote and provide equity in education; to provide technological skills necessary to compete as students and workers; to create life-long, confident, independent learners that are prepared for high school and beyond. SBC-LTER is collaborating with LCJHS through MSP.

American Assoc. Univ. Women Tech Trek

Tech Trek is a math/science camp designed to develop interest, excitement and self-confidence in young women who will enter eighth grade in the fall. It features hands-on activities in math, science and related fields. All sleeping, eating, instructional and recreational facilities are located on a university campus where camps are held. Tech Trek is a new SBC Schoolyard partner.

LTER Math-Science-Partnership (MSP)

The project connects the research and education prowess in the environmental sciences of universities and sites within LTER with teacher professional development in science and mathematics of partner middle schools and high schools. It extends across the nation and involves four LTER research sites?the Shortgrass Steppe, Baltimore Ecosystems Study, Kellogg Biological Station, and Santa Barbara Coastal?and their partnering institutions, the LTER Network Office, and a group of 22 K-12 schools and districts that will directly impact over 250 science and mathematics teachers and 70,000 students from diverse backgrounds.

Other Collaborators or Contacts

The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) is a large-scale marine science research program funded by the David and Lucile Packard Foundation that focuses on understanding the nearshore ecosystems of the U.S. West Coast. Representing a collaboration of scientists from four universities (including UCSB), the interdisciplinary research ranges from long-term monitoring of ecological and oceanographic processes at dozens of coastal sites to experimental work in the lab and field to explore how individual organisms and populations are affected by environmental change. PISCO research at UCSB (PIs Gaines, Warner, and Washburn) is tightly linked with the Santa Barbara LTER and considerable sharing of resources and data in studies pertaining to physical, chemical, and biological oceanography. (http://www.piscoweb.org)

NASA funds a long-term (>10 yr) study at UCSB (referred to as Plumes and Blooms) (http://www.icess.ucsb.edu/PnB/PnB.html)that investigates marine plankton blooms associated with runoff. The goal of this project (Lead PI Siegel) is to develop new satellite ocean color algorithms to use in coastal waters influenced by terrigenous materials (sediments, dissolved organic materials, etc.). In situ optical quantities and in-water constituents are collected every two weeks along a 7 station transect crossing the Santa Barbara Channel and related to simultaneous ocean color images from the SeaWiFS satellite sensor. Siegel is also the lead PI on another NASA funded project whose research objective is to develop a predictive understanding of giant kelp forests in the nearshore waters of California using a combination of: (1)

high-resolution remote sensing of kelp cover, biomass & its physiological state, (2) metapopulation modeling of kelp patch dynamics, and (3) Bio-optical modeling of kelp productivity. The project builds on the findings of SBC funded research and there is substantial coordination and information exchange between the two projects.

The San Onofre Nuclear Generating Station (SONGS) mitigation program was instituted by the California Coastal Commission as a means of compensating for the loss of coastal marine resources caused by the operation of the nuclear power plant, which is located on the coast in northern San Diego County. PI Reed and Associate Investigator Page are lead investigators on the SONGS mitigation program and are responsible for designing and implementing monitoring programs that evaluate the effectiveness of the various mitigation projects. One component of the mitigation program requires the restoration of tidal wetlands. Carpinteria salt marsh is one of the reference sites being used to evaluate the performance of San Dieguito Lagoon (the wetland to be restored, which is located in San Diego County). Data on water quality, tidal inundation, and species composition and abundance of wetland biota are being collected at Carpinteria and three other wetlands in southern California as part of this project. These data are available to us and nicely complement those that are being collected by SBC LTER. Another large component of the SONGS mitigation program involves mitigating the loss of kelp forest habitat via the creation of artificial reefs. The design of the long term-monitoring of the artificial reef and nearby natural kelp forests that are used for reference is similar to that used by SBC LTER to monitor changes in kelp forests in the Santa Barbara region and provides an excellent opportunity for regional comparisons.

SBC investigators are actively collaborating with researchers from the Centre of Marine and Environmental Research (CMER) at the Universidade do Algarve, Portugal on issues pertaining to gene flow, inbreeding depression and population connectivity in the giant kelp Macrocystis pyrifera. CMER is a member of the Marine Biodiversity and Ecosystem Functioning (MarBEF) program, which is a network of excellence funded by the European Union. It consists of 91 European marine institutes and is a platform to integrate and disseminate knowledge and expertise on marine biodiversity with links to researchers, industry, stakeholders and the general public. CMER is also a member of CORONA (Coordinating Research of the North Atlantic), an NSF-funded multidisciplinary research network to study the marine biota of the North Atlantic. The network includes 118 scientists from 13 countries across the North Atlantic. The major research and education goals of CMER, MarBEF, and CORONA are complimentary to those of SBC LTER, providing the ideal opportunity for collaboration.

The University of California, Santa Barbara?s Academic Preparation and Equal Opportunity (APEO) program mission is to serve a diverse population by supporting and providing pathways of high-quality P-20 academic preparation and equal opportunity programs consistent with university, state and federal policies related to student enrollment and retention and faculty and staff hiring through partnerships within the university and the larger community. APEO has provided additional funds for undergraduate student salaries for Schoolyard related programming

SBC-LTER investigators are collaborating with the California Cooperative Extension/Sea Grant program on projects investigating aquatic invasive species and on collaborative fisheries research with fishing partners.

CALobster (http://www.calobster.org/), a collaborative fishery research program initiated by an SBC investigator and his graduate students, focuses on the spiny lobster fishery with a goal of promoting and conducting community-based research that lead to the best management practices and help maintain working harbors.

Activities and Findings

Research and Education Activities: (See PDF version submitted by PI at the end of the report)

Findings: (See PDF version submitted by PI at the end of the report)

Training and Development:

Education and training are tightly integrated into all aspects of SBC research. As of August 2009, 10 post docs, 37 graduate students, 8 REU students and more than 100 undergraduate students have participated in SBC research during the last 3 years. SBC provides research training opportunities to more than 25 undergraduate students each year. In addition to gaining valuable research experience, many of the undergraduate students earn academic credit or received monetary compensation for participating in SBC research as interns and honors students. SBC investigators, graduate students and staff train mentor independent research by undergraduates and local high school students. SBC LTER is an active participant in NSF's Research Experience for Undergraduates program and in several other mentorship programs sponsored by the University of California. REU students work closely with SBC researchers on both core measurements and experimental

studies in the kelp forest. In addition to its pivotal role in SBC?s K-12 and public outreach programs (see above), the Schoolyard program (SLTER) at SBC provides our undergraduate interns with a rigorous and pedagogically sound program of training in marine science and science education through The REEF (Research Experience and Education Facility) and other programs. These interns engage directly with middle school students as teachers and role models. Our project's research regularly finds its way into the classroom as SBC investigators routinely incorporate activities and findings of SBC-sponsored research into their teaching, thereby extending the project's contributions to the broader student body. Many SBC investigators give guest lectures and class demonstrations on SBC research in university courses.

SBC graduate student and postdoctoral training is integrated with a variety of other programs on the UCSB campus including the Bren School of Environmental Science and Management, The Institute for Computational Earth System Science, The Interdepartmental Marine Science Program and the Partnership for Interdisciplinary Studies of the Coastal Ocean. With the SBC LTER, these programs promote interdisciplinary research to examine how coastal ecosystems change in response to natural and human-induced alterations in the environment. SBC training includes students and post docs working in terrestrial, aquatic, and marine environments with interests ranging across ecology, physiology, geology, hydrology, oceanography, modelling and coastal policy. This enables valuable cross-training on environmental issues pertaining to coastal ecosystems, provides a common language for communicating scientific information on these issues, and contributes to the creation of a diverse scientific community of students and postdocs that fosters a respect and appreciation for other disciplines. SBC students, postdoctoral fellows, and investigators participated in the LTER All Scientists Meeting in 2009 and the site review. At these meetings, results from SBC research and collaborative projects were presented in poster sessions and oral presentations. SBC graduate students also participated in the first UC-LTER graduate postdoc symposium organized by the CCE-LTER in May 2008.

Educational opportunities at SBC are not limited to university students and post docs. Teachers and numerous volunteers from the general public regularly participate in our stream sampling program and gain considerable knowledge on the constituents of runoff and of the processes that influence their concentrations.

Outreach Activities:

The SBC-LTER Summer Diversity Program 2009

SBC?s Schoolyard LTER (SLTER) program is organized around a theme of watershed ecology. This approach allows for an integrated program that includes K-12 students, K-12 teachers, undergraduate and graduate students, and staff. In 2009 we are focusing on developing long-term connections with local, regional and state middle and junior high schools through a partnership with American Association of University Women (AAUW) - Tech Trek Program. Tech Trek is a math/science summer program designed to develop interest, excitement and self-confidence in young women who will enter eighth grade in the fall. It features hands-on activities in math, science and related fields. Tech Trek is a campus residential program that includes educational and recreational activities, all of which are located on a university campus where camps are held. Tech Trek is part of an interdisciplinary partnership involving science, technology, engineering, and math (STEM) departments at UCSB, through the Office of Academic Preparation and Education Outreach (APEO). The goal of APEO is to build college-going communities that improve student learning, increase college-going rates in underrepresented populations, and provide equal access to higher education for California?s diverse students. With the infrastructural support of Tech Trek and APEO, the SBC SLTER program also aims to engage middle school students and teachers through the academic year and summers, and throughout their secondary school education.

Program Format: We are using the successes we had with our LACC summer program (2004-2007) and Pathways program (2008) to guide development of our SBC SLTER program. First, we continue to work with our undergraduate interns in a rigorous and pedagogically sound program of training in marine science and science pedagogy. These interns engage directly with middle school students as teachers and role models. Second, we continue to develop and adapt marine science lesson plans that engage students with learning about their local environment. These lesson plans incorporate ongoing SBC LTER research and include working with data generated by monitoring and experiments. The program is developed to build student?s skills in scientific inquiry through a series of activities that move from structured or guided investigation to open-ended experimentation. Third, our program includes a combination of school-based activities, field trips, and an on-campus residential experience that immerses students in the environment of a college campus.

In working with Tech Trek, the SBC SLTER program engages a highly diverse group of over 90 girls from junior high and middle school from across the state. The participants are diverse, representing a broad range of socioeconomic and demographic groups. During their week-long residential immersion at UCSB, students participate in ?core? courses that focus on science basics: physics, math, chemistry, and biology. These courses are then complimented with practical application activities where students are engaged in SBC LTER research- based learning activities, conduct field research, and explore the possibility of attending a 4-year college. Activities include explorations of ecology and adaptation at the UCSB aquarium, SBC LTER research site monitoring protocols, and a Floating Lab trip, on a 75? catamaran, into the Santa Barbara Channel.

An additional benefit expected in future years is the long-term connection we will maintain with participating students both through APEO support (they work with some of these same students throughout their high school years) and through continued engagement with students as they move into high school and college. We envision a program that supports interested students with science fair projects, summer research

opportunities, and mentoring opportunities with our middle school program.

Research Experience & Education Facility (REEF)
The Santa Barbara Coastal (SBC) LTER outreach, education and training programs benefit from a close association with the University of California at Santa Barbara?s Research Experience & Education Facility, better known as the REEF, an interactive aquarium facility. The REEF is equipped with state-of-the-art, aquaria and touch tanks, ranging from 2 to 2,000 gallons. The REEF also utilizes a high-tech life support system for the Research Tank, which highlights current, on-going research at UCSB and the Marine Science Institute, including SBC and MCR LTER research.
One of the joint goals of the SBC LTER and the REEF program is to provide UCSB undergraduates, majoring in Aquatic Biology, with a solid foundation in temperate marine ecology and research. The REEF training provides them with the basis for communicating this knowledge in an educational format. To that end, the REEF develops its curriculum around a number of research programs at UCSB. The SBC LTER is a significant contributor to this endeavor. Support from the SBC LTER schoolyard program has allowed the REEF to obtain teaching supplies and equipment for curriculum and teacher professional development, as well as provide stipends for teachers, undergraduate and graduate internships. The REEF also utilizes graduate students from the SBC LTER to train REEF undergraduate staff, which, in turn, enhances their training as laboratory and field assistants and research divers for SBC LTER research.
The REEF program has been busy during 2009, between outreach visits to schools, community events and on-campus programs, the REEF provided marine science and environmental education to over 15,000 of children and adults. This includes hosting educational visits from primary and secondary schools from King City in Monterey Co., to San Diego, and as far east as Las Vegas, Nevada! The REEF also serves as a marine laboratory for many colleges including Cal Lutheran Thousand Oaks, CSU Channel Islands, and UCSB. At UCSB, the REEF serves as an interdisciplinary adjunct laboratory for undergraduate courses including: Geology 4 (Intro to Oceanography), EEMB 3 (Intro Biology), EEMB 106 (Biology of Fishes), Writing 2 and Writing 109 ST. This year the REEF had over 3,200 on-campus visitors. The REEF also serves UCSB outreach and summer programs, including the SBC-LTER Schoolyard Program.

OceansAlive!
SBC LTER students participate in the OceansAlive! program of the UCSB Marine Science Institute (MSI), a collaboration with a number of UCSB departments and research programs to provide 125 local junior high, middle school and high school students with UCSB undergraduate and graduate student mentors for science fair projects. These secondary school students then compete at the local level with the opportunity to progress to the state and national levels.

Math-Science-Partnership (MSP)Project: Pathways to Environmental Literacy
The MSP project, which was launched in October 2008, connects the research and education strengths in the environmental sciences of universities and sites within LTER with teacher professional development in science and mathematics of partner middle schools and high schools. It extends across the nation and involves four LTER research sites?the Shortgrass Steppe (SGS), Baltimore Ecosystems Study (BES), Kellogg Biological Station (KBS), and Santa Barbara Coastal (SBC) and their partnering institutions, the LTER Network Office, and a group of 22 K-12 schools and districts that will directly impact over 250 science and mathematics teachers and up to 70,000 students from diverse backgrounds. The SBC LTER site is currently working with La Cumbre Junior High School in providing teacher professional development to develop in-class science curriculum based on SBC LTER field study sites, data and ecological principles.

Other SBC Outreach Activities
Direct outreach to the public is an active area for many SBC investigators and students. Al Leydecker, an SBC post-doctoral fellow, assists and helps direct stream and river monitoring, education and sampling programs for several community environmental organizations, including Santa Barbara Channel Keeper, Ventura Surf Rider and the Friends of the Santa Clara River. Co-investigators Bradley Cardinale and Jenifer Dugan gave talks to the lcoal groups including Audobon Society and the Santa Ynez Natural History Society.
SBC investigators also serve as participants and advisers to several community groups to provide educational and a scientific perspectives including the Santa Barbara Community Environmental Council, Friends of the Santa Clara River, Santa Barbara Creeks Council, and the UCSB Shoreline Preservation Fund.

Journal Publications

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Web/Internet Site

URL(s):

http://sbc.lternet.edu/index.html

Description:

This is the project website which describes the research questions, progress, people, outreach. publications, presentations and data products of the Santa Barbara Coastal LTER. The SBC website was converted from a collection of static pages to a scripted system which streamlines the addition of new material and facilitates editing of dynamic menus or style changes. During the conversion, new material was added so that the website is now compliant with LTER recommendations.

Other Specific Products

Product Type:

Data or databases

Product Description:

SBC publications database: Like our datasets, SBC publications are described by the EML schema. We have continued to extend EML for the reporting and multi-use needs of bibliographic references. We are also continuing work on the web application to accommodate searches and reports, and to increase speed.

Sharing Information:

SBC Publications database is available at http://sbc.lternet.edu/publications

Product Type:

Software (or netware)

Product Description:

Query interface for EML datasets: SBC's growing data time series requires tools for querying and sub-setting data tables. We have developed a generic web application which can be applied to many types of data tables described by EML. The application's use of the EML format means it can potentially be applied by many other research groups.

Sharing Information:

This query interface is available through links at http://sbc.lternet.edu/data).

Product Type:

Data or databases

Product Description:

SBC datasets on climate, hydrology, stream chemistry, watershed characteristics, coastal ocean currents and biogeochemistry, net primary production of kelp, historical kelp biomass, cover of sessile organisms on reefs, reef fish abundance, abundance and size of giant kelp, reef invertebrate and algal density and stable isotope data from kelp forest food webs are being collected and updated annually.

Sharing Information:

Available final datasets are listed in the metadata catalog on the site's website http://sbcdata.lternet.edu/catalog/

Contributions

Contributions within Discipline:

The understanding of ecosystem level processes in giant kelp forests has lagged behind the increasing body of knowledge at the species, population, or community level for of kelp forests over the last four decades. Results from our reef studies are helping to address the growing need for research at the ecosystem level in kelp forests. Of particular significance are our studies of 1) primary production, 2) stable isotope analyses of kelp forest food webs, 3) the role of nutrients in altering these food webs and 4) links between kelp forests and sandy beach food webs.

Our coastal ocean research has identified several physical transport mechanisms important for delivering nutrients to kelp forest ecosystems. Examples include upwelling, runoff, and internal tides, and we have are quantitatively assessing the flux of nutrients due to each mechanism. This research is providing valuable information about transport processes on the inner shelf, which are poorly understood. Quantifying fluxes into and out of the inner shelf is extremely important for understanding the cross-margin transport of carbon, nutrients, and sediments. Most inner-shelf process studies to date have been done on the Atlantic coast of North America. Our work in the Santa Barbara Channel thus fills an important gap and is one of the first studies to focus on a coastal upwelling system.

Our oceanographic research is also helping to further our understanding of physical mixing of freshwater plumes as they enter the coastal ocean. Satellite ocean color estimates of sediment content show that less than 0.01% of sediment discharged in runoff events remains suspended in offshore plumes. Presumably the remainder settles quickly onto the inner-shelf substrate, and some of it may then be redistributed through resuspension or via buoyancy-driven flows. Our measurements will be important for determining the fate of this sediment, and this may have important consequences for the distribution of nutrients after the runoff season is over. Our moored instruments, with their combination of hydrographic and biological sensors allow us to measure outflow events even from very small streams. This allows us to better characterize the transport of materials from land to ocean ecosystems.

Our extensive and intensive measurements and models of solute and particulate concentrations and export from the steep, flashy catchments along the central/southern coast of California provide important comparative information to the field of watershed science that is otherwise lacking. The hydrologic model that we are developing will aid in predicting how climate, land-use, and the physical and biological structure of coastal streams influence the runoff of material constituents. The model simulates rainfall-runoff and routing processes from three sources (surface, shallow soils and groundwater) for both undisturbed and urban lands and will ultimately be integrated with water quality modules to simulate the discharge of water, associated solutes, and sediments from the land to the ocean.

Contributions to Other Disciplines:

The research mission of SBC is very interdisciplinary in scope. As such, our research contributes to a wide range of disciplines including: terrestrial, aquatic and marine ecology, physical, biological and chemical oceanography, hydrology, geology, geography, toxicology, environmental history and informatics. Coordinated studies among the many disciplines represented in SBC are leading to an improved understanding of the patterns and processes that link land and ocean environments and their consequences for coastal ecosystems. This improved understanding is not only contributing to furthering the many disciplines listed above, but is of considerable value to those interested in studying the extent to which society is influenced by human impacts to coastal systems. SBC is actively initiating ties with the social science community. Investigator Melack is the acting dean of the Bren School of Environmental Scienc and Management and has played a pivotal role in the development of the Bren School, including chairing the committee that wrote the original proposal for the school. The Bren School?s graduate training programs integrate science, management, law, economics, and policy as part of an interdisciplinary approach to environmental problem-solving. Investigator Siegel directs the Institute for Computational Earth System Sciences (ICESS) which is a leader in ocean color and remote sensing research. Investigator Lenihan leads a collaborative fishery research program, CALobster

(http://www.calobster.org/), focused on the spiny lobster fishery with a goal of promoting and conducting community-based research that lead to the best management practices and help maintain working harbors. Investigators Page and Dugan conduct collaborative research on crab fisheries with local trap fisherman. Dugan and Guerrini are writing an interdisciplinary multi-authored book on the deep human and environmental history of a SBC coastal wetland and watershed.

Contributions to Human Resource Development:

Our project provides significant opportunities for research and teaching in science at multiple levels. As of August 2009 10 post docs, 37 graduate students, 8 REU students and more than 100 undergraduate students have participated in SBC research during this funding cycle. In addition to gaining valuable research experience, many of the undergraduate students earned academic credit or were given monetary compensation.

Our project's research also finds its way into the classroom as SBC investigators routinely incorporate activities and findings of SBC-sponsored research into their teaching, thereby extending the project's contributions to the broader student body. Many SBC investigators give guest lectures and class demonstrations on SBC research to university courses. SBC investigators, graduate students and staff work with undergraduate students including interns and honors students and mentor independent research by undergraduates and high school students.

Educational opportunities at SBC are not limited to university students and post docs. Pre-college teachers and non-scientists from the local community routinely participate in our ongoing stream sampling program and gain considerable knowledge on the constituents of runoff and of the processes that influence their abundance.

Increased exposure to the SBC research activities has come by way of the LTER Schoolyard program. In 2008, SBC has continued to increase the exposure of SBC research activities to K-12 students and teachers by developing an exciting new environmental education program for middle school students. The new program partners with local middle schools through a partnership with UCSB?s Office of Academic Preparation and Education Outreach (APEO) for environmental education programs including field trips, an educational cruise and individual research projects. The goal of APEO is to build college-going communities that improve student learning, increase college-going rates, and provide equal access to higher education for California?s diverse students.

The Santa Barbara Coastal (SBC) LTER outreach, education and training programs benefit from a close association with the University of California at Santa Barbara?s Research Experience & Education Facility, better known as the REEF, an interactive aquarium facility. The REEF is equipped with state-of-the-art, aquaria and touch tanks, ranging from 2 to 2,000 gallons. The REEF also utilizes a high-tech life support system for the Research Tank, which highlights current, on-going research at UCSB and the Marine Science Institute, including SBC-LTER research. This program reaches thousands of students annually through special programs, school group tours and school visits.

SBC-LTER hosted the inaugural workshop for a new NSF funded project on targeted partnerships in math and science in July 2009. These targeted partnerships focus on the critical education junction of middle school through high school to develop a program of teacher professional development in science and mathematics driven by framework of environmental science literacy surrouding the learning progressions of core science and math concepts. The goal is to connect the research capabilities of partner universities and LTER sites with K-12 teacher professional development in science and math at partner schools.

Contributions to Resources for Research and Education:

Physical resources

NSF funds from our project are used to maintain a custom 22' research vessel that is specially designed for scuba and oceanographic research. Other research groups on the UCSB campus have access to this vessel for their research needs as well.

Information Resources

SBC's website contributes to information resources by providing the scientific community and the general public access to unique datasets that are of interest to a diverse array of people. Some examples of such datasets include: historical data on giant kelp abundance in the northeast Pacific, SST imagery from NOAA-AVHRR polar orbiters of the Santa Barbara Channel, high frequency radar data of surface currents in the Santa Barbara Channel, precipitation data and soil mapping and land-use coverage of the Santa Ynez Mountains. In 2009 access and format of these datasets were enhanced on our website which was redesigned to fit LTER network standards and updated for content.

Contributions Beyond Science and Engineering:

SBC investigators have been very active in applying their knowledge of Santa Barbara's coastal ecosystems to inform and implement changes in local and regional policies. SBC investigators serve as advisors and committee and board members for a number of local and national groups concerned with conservation and management of natural resources.

Investigator Gaines serves on several committees and advisory groups concerned with fisheries and marine conservation including the Science

Advisory Panel for the California Marine Life Protection Act, , the Science Advisory Group for the Interagency Ecological Program of the California Department of Water Resources, the Joint Ocean Commission and the Marine Life Protection Act Baseline Science Management Panel. Other SBC investigators are actively working with the Science Advisory Panel and stakeholder groups to integrate SBC data and core measurements, provide information needed to develop the regional profile and evaluate proposals for reserve network design for the south coast region.

Investigators Reed and Page work with the staff of the California Coastal Commission (CCC) on a large multidimensional program designed to mitigate for the loss of coastal marine resources caused by the operation of the San Onofre Nuclear Generating Station (SONGS), a coastal power plant located in north San Diego County. The major emphasis in this program is compensation for lost marine resources via wetland and kelp forest restoration. Reed and Page?s primary responsibilities are to consult with the employees of the power plant (Southern California Edison), the CCC and their staff, and other resource agencies on ecological issues relating to the design of the mitigation projects and to develop and implement monitoring programs capable of determining whether the biological and physical performance of these projects meet pre-determined standards. Much of the science done on these mitigation projects is quite complementary to that done by SBC LTER and there is considerable exchange of information and ideas between the two projects.

SBC research plays a prominent role in shaping policy towards local watershed issues as well. We have developed mutually beneficial, cooperative associations with local government departments and NGOs. Santa Barbara County's Project Clean Water is engaged in sampling local creeks during the initial rise of the hydrograph and measuring a suite of pollutants including metals, pesticides and herbicides. Our intensive sampling of nutrients and particulates during the entire hydrograph for most storms complements the County's effort, and they and we share our data and interpretations. We perform nutrient analyses on water samples from local streams and rivers for Santa Barbara Channelkeepers, the City of Santa Barbara and the Friends of the Santa Clara River. The Santa Barbara Channelkeeper program conducts monthly collections along the Ventura River, and we participate in this fieldwork and complement their in situ measurements with high quality nutrient chemistry. Co-Investigator Melack is on the Technical Advisory Committee for Friends of Santa Clara River water quality monitoring program. Al Leydecker, a SBC post doc, continued to assist and help direct stream and river monitoring, synthesis, education and sampling programs for several community environmental organizations including Santa Barbara Channel Keeper, and Ventura Surfrider in 2009. He also provided regular reports on the status of algal blooms and eutrophication to interested parties involved in the TMDL regulatory process managed by the Regional Water Board. Investigator Cooper is a member and consultant for the Tidewater Goby Working Group of the City of Santa Barbara, Public Works Department.

Three major fires, the Gap Fire in July 2008, Tea Fire in November 2008 and the Jesusita Fire in May 2009, have occurred in the Santa Barbara area, resulting in large scale evacuations of residents and the loss of nearly 300 homes and. The total acreage burned in less than one year in these three fires exceeds 20,000 acres of watershed lands located in and above the cities of Santa Barbara, Montecito and Goleta. SBC collects data that will help evaluate the effects of these 3 major fires on the composition of runoff and stream discharge in a variety of catchments. SBC investigators Cooper and Melack are working with NGOs and county and federal agencies to document effects of the fires and contribute to planning and preparation for post fire impacts. A group of SBC investigators are building collaborations and pursuing support for more intensive studies of the burned catchments.

The conservation and management of sandy beach ecosystems lags behind that of coastal wetlands and riparian habitats. SBC research on kelp wrack in these ecosystems has led to the recognition of wrack as an ecological resource by local and state agencies and contributed to the development of new policies for coastal management. SBC investigators Dugan and Page are working with California State Parks to develop and evaluate new restoration stratrgies for wrack-associated invertebrates on beaches that support breeding snowy plovers, a federally listed shorebird. Dugan plays an active advisory role with coastal consortiums and groups concerned with improving the conservation and management of beach ecosystems. She was invited to become part of the NSF-funded Coastal Barrier Island Network (CBIN) which is developing an interdisciplinary network to address the effective management of barrier island ecosystems under the pressure of global climate change (e.g., sea level rise and increased hurricane activity) and continued urbanization. She is a member of the Beach Ecology Coalition, a new professional organization for beach managers, that provides a forum for education, outreach, training and development of best practices and cooperative research on sandy beach ecosystems in California.

Conference Proceedings

Special Requirements

Special reporting requirements: None

Change in Objectives or Scope: None

Animal, Human Subjects, Biohazards: None

Categories for which nothing is reported:

Any Conference

Research Activities

The Santa Barbara Coastal Long Term Ecological Research (SBC LTER) program (http://sbc.lternet.edu/index.html) was established in April 2000 and is housed at the University of California Santa Barbara. Its overarching objective is to understand the linkages among ecosystems at the land-ocean margin through interdisciplinary research, education and outreach with a focus on developing a predictive understanding of the structural and functional responses of giant kelp forest ecosystems to environmental forcing from the land and the sea. Giant kelp forests occur on shallow rocky reefs that fringe temperate coastlines throughout the world and are highly important to the ecology and economy of the regions in which they occur. Our principal study site is the semi-arid Santa Barbara coastal region, which includes steep watersheds, small estuaries, sandy beaches, and the neritic and pelagic waters of the Santa Barbara Channel and the habitats encompassed within it (e.g., giant kelp forests, deep ocean basins, pelagic waters and offshore islands).

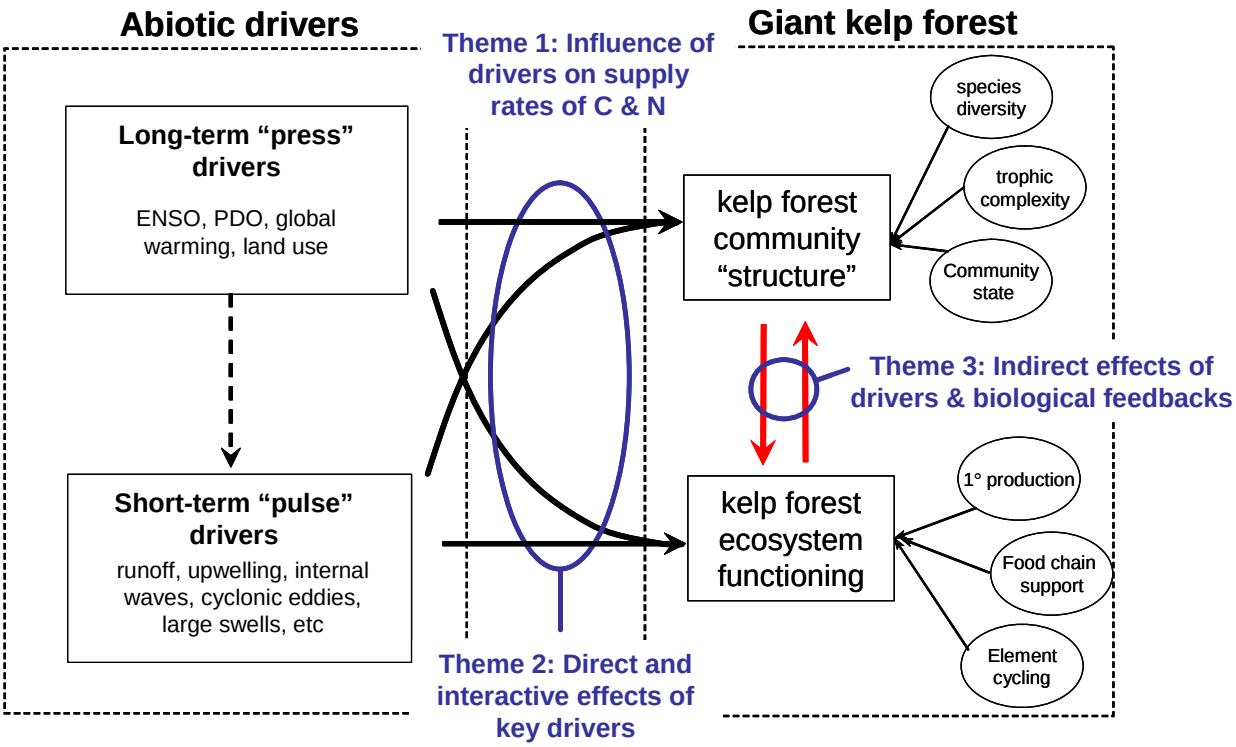
During our first six-year funding cycle our research focused on testing hypotheses and addressing questions relating to the role of terrestrial, oceanic and atmospheric forcing in accounting for the dynamics that we observed in kelp forest structure and function. Much of this work centered on: (1) determining the dynamics of production and food web structure in kelp forests, (2) identifying the important processes on land and in the coastal ocean that drive changes in the nature and quantity of subsidies delivered to kelp forests, and (3) establishing sampling programs to generate long-term data sets that could address questions and hypotheses relating to the core areas of LTER research. This research led to substantial increases in our knowledge of our study system. Armed with this increased knowledge we followed the advice of our first mid-term review and reduced our sampling effort in a number of these areas in our second cycle of funding in order to more intently pursue linkages among ocean, reef and land components and their propensity to change under different environmental conditions.

Our ability to predict how coastal ecosystems will respond to environmental change requires a recognition that the drivers of change (e.g., climate, disease, human actions, and disturbances such as fires and ENSO events) typically act over different temporal and spatial time scales. This inevitably results in a complex set of interactions among the biotic responses that these forcings elicit. The LTER Network has long been interested in environmental drivers that span a range of temporal and spatial scales and have recently formalized this interest into a pulse/press framework in which abiotic drivers act in a chronic long-term (i.e., “press”) or periodic short-term (i.e., “pulse”) fashion to influence biotic structure and ecosystem function (LTER Decadal Plan 2007). We adopted this framework for our current funding cycle which seeks to obtain a more predictive understanding of the importance of land and ocean processes in determining the structure and function of giant kelp (*Macrocystis pyrifera)* forest ecosystems. The overarching question motivating our current research is:

> *How do abiotic drivers acting over different spatial and temporal scales influence kelp forest structure and function and its interactions with adjacent ecosystems?*

To address this question we have focused our research around three general themes (Figure 1): (1) The influence of abiotic press and pulse drivers on exchange rates of N and C between giant kelp forests and adjacent land and ocean habitats, (2) The direct and interactive effects of key press and pulse drivers on kelp forest community structure and function through the modification of nutrient supply and wave disturbance, and (3) The indirect effects of pulse and press drivers on kelp forest community structure and function and the feedbacks between structure and function.

Figure 1. Conceptual framework of SBC LTER research. Specific research questions and hypotheses are organized under one of three central themes. The solid black arrows represent the influx of physical disturbance and chemical subsidies as influenced by abiotic press and pulse drivers. The ecological consequences of interactions between press and pulse drivers (dashed arrow) are manifested over a time period that is greater than the current six-year funding cycle, which necessitates the need for long-term research



THEME 1**:** The influence of abiotic press and pulse drivers on the rates of delivery of N and C to giant kelp forests

- *QUESTION 1a. How are the rates of delivery of N and organic C to giant kelp forests from terrestrial and oceanic environments altered by press and pulse drivers?*
- *QUESTION 1b. What are the sources and fate of dissolved and particulate organic matter in the nearshore zone?*

THEME 2: The direct and interactive effects of key press and pulse drivers on kelp forest community structure and function through the modification of nutrient supply and wave disturbance

- *QUESTION 2. How do wave disturbance and N loading act and interact to influence the structure, function, and resilience of the kelp forest ecosystem?*

THEME 3: Indirect effects of pulse and press drivers on kelp forest community structure and function and the feedbacks between them.

- *QUESTION 3a. How does the negative effects of giant kelp on understory algae and phytoplankton interact with wave disturbance and N loading to affect the magnitude and interannual variability of NPP of the kelp forest ecosystem?*
- *QUESTION 3b. How does the forest interact with its flow environment to modify the delivery of N and C and influence the species composition and performance of kelp forest biota?*

Short-term (hours to weeks) abiotic drivers that affect the delivery of nutrients and organic matter to kelp forests (e.g., upwelling, runoff) are embedded within a climatic regime (i.e., press driver) that fluctuates over much longer time scales (years, decades or more). The rate at which nutrients and organic matter are exchanged between kelp forests and adjacent habitats will depend not only on the direct effects of the pulse and press drivers, but also on the interactions among them (Theme 1, Figure I.1). Abiotic drivers not only influence supply rates of N and C to kelp forests, but also the frequency and intensity of physical disturbance. Because the return interval of some of the key press drivers occurs on decadal and longer time scales, long-term research is needed to evaluate the ecological consequences of the direct and interactive effects of pulse and press drivers on the structure and function of giant kelp forests (Theme 2, Figure1). Like most natural systems, the structure and function of a giant kelp forest are inextricably linked. Thus, abiotic pulse and press drivers that directly affect the abundance and species composition of a kelp forest community will indirectly influence the system's capacity to fix carbon and take up nutrients used to support the complex kelp forest food web (Theme 3, Figure1). Similarly, the amount and form of organic matter produced by the forest and made available to kelp forest consumers will in turn influence the abundance and species composition of organisms inhabiting the forest. Positive and negative feedbacks between kelp forest structure and function may arise from these indirect effects.

Site characteristics

SBC LTER is ideally suited to explore issues of connectivity between terrestrial and marine ecosystems and the actions and interactions of pulse and press drivers on kelp forest structure and function. Our site is bounded by the Transverse Ranges of central and southern California to the north, the Channel Islands to the south, Pt. Conception to the west, and the Santa Clara River to the east (Figure 2). The catchments draining into the Santa Barbara Channel offer a rich diversity of watersheds that are characterized by a wide variety of land covers and uses. Giant kelp forms expansive forests on shallow rocky reefs, which dominate the nearshore in this region. Because of their close proximity to shore, kelp forests are influenced by physical and biological processes that occur on the land as well as in the open ocean (Figure 3). Streams and rivers transport nutrients, dissolved and particulate organic matter (DOM and POM), sediments, and pollutants from coastal watersheds to kelp forests, while ocean currents, internal waves, and other oceanographic processes supply nutrients, DOM, POM, larvae and plankton from adjacent offshore waters. In return, kelp forests export large amounts of DOM and POM to inshore intertidal habitats, as well as to offshore deep-water habitats. The transport of nitrate into the euphotic zone and disturbance from storm-generated waves are arguably the two most important factors regulating the standing crop and production of macroalgae (including giant kelp) in the coastal waters of southern California, and our research themes emphasize these two aspects. Short-term (i.e., pulse) and long-term (i.e., press) changes in climate,

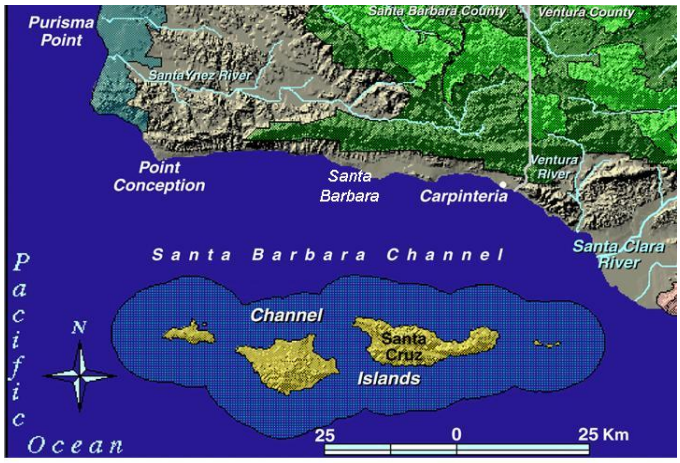


Figure 2. Regional map of SBC LTER. The site boundaries extend from Pt.Conception in the west to the Santa Clara River in the east, from the top of the Santa Ynez Mountains in the north out to the Channel Islands.

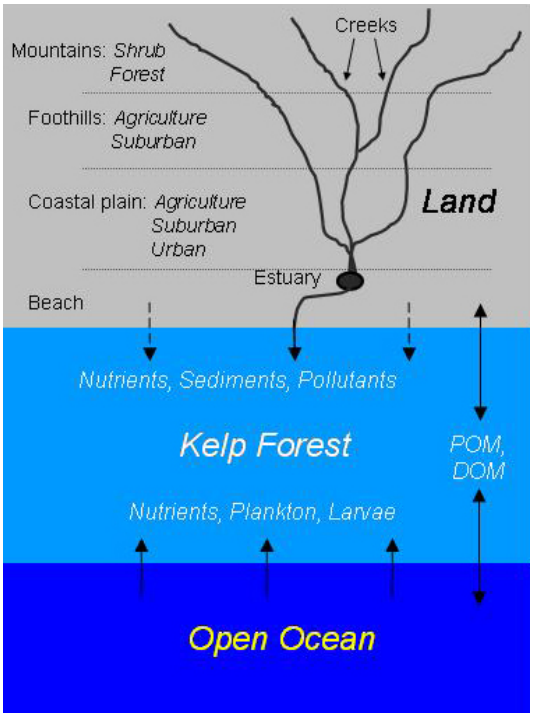


Figure 3. Material exchange between kelp forests and adjacent land and ocean ecosystems

oceanography and land use or disturbances such as fire that directly or indirectly alter the disturbance regime and/or the supply of nutrients can have a profound influence on the structure of kelp forest communities and on the flow of materials to and from them.

The Santa Barbara region has a Mediterranean climate characterized by relatively calm, dry conditions in summer and autumn, prevailing winds in the spring, and episodic rain storms in the winter. This environmental setting creates strong seasonality in bottom-up forcing (via variation in the supply of nitrogen) and top-down control (via physical disturbance from storm generated waves). A number of "pulse" drivers operating on seasonal time scales influence these bottom-up and top-down forces including terrestrial runoff, large oceanic swells, wind-driven upwelling, internal waves, and other less understood oceanographic processes that supply nitrogen to otherwise depleted surface waters in summer and fall, and are thought to be important in enabling giant kelp to persist and grow year round in most years.

Aside from the seasonal cycle, the El Niño Southern Oscillation (ENSO) is the dominant climatic signal over most of the Pacific Ocean. The two phases of ENSO are generally termed El Niño (the warm, nutrient-poor phase) and La Niña (the cool nutrient-rich phase). The strengths of the various pulse drivers are El Niño dependent causing the relative contributions of land- and ocean-derived nitrogen and carbon to kelp forests in southern California to vary between El Niño and La Niña years, while the strength and intensity of El Niños vary with longer-term climatic cycles that have return frequencies of decades (e.g. the Pacific Decadal Oscillation).

General Research Approach

Certain abiotic drivers of kelp forest ecosystems are readily manipulated (e.g., physical disturbance that removes kelp), while others are difficult or practically impossible to manipulate on a meaningful scale (e.g., sea surface temperature, water column productivity, elevated runoff, land use change). Because of this, our research relies on a variety of approaches that include: (1) Coordinated long-term measurements of key abiotic drivers and ecological response variables. The purpose of our long-term measurements is to elucidatel spatial and temporal patterns in the structure and function of giant kelp forests in the Santa Barbara Channel and in the physical and chemical forcing variables that influence them. Because kelp forests occur at the land-ocean margin, we collect long-term measurements on land and intertidal beaches, in the offshore ocean, and in the shallow coastal zone where kelp forests occur (Table1), (2) Manipulative field experiments designed to isolate the causal mechanisms underlying the patterns observed in long-term measurements, (3) Measurement-intensive process studies aimed at obtaining a mechanistic understanding of processes that cannot be isolated using manipulative experiments, and (4) Integrated synthesis using modeling and analyses that allow for predictions beyond the spatial and temporal scope of our data, and that help guide the direction of our future research. Collectively, these elements provide a

powerful basis for building a greater understanding of the direct and indirect effects of pulse and press drivers on kelp forest ecosystems, which is essential for predicting how giant kelp forests will respond to ongoing changes in the environment.

Table 1. Long-term core monitoring performed by Santa Barbara Coastal LTER (data available via the SBC LTER website http://sbc.lternet.edu/data/.)

Title	Summary of measurements	Year initiated
Watershed Hydrology and Stream Chemistry:		
Precipitation	Rainfall at 12 stations	2003
Stream Discharge	Stream stage and discharge at 16 stations	2002
Stream Chemistry	Storm-flow and base-flow sampling of nutrients, major anions and cations at 8 stations	2001
Ocean Physics & Biogeochemistry:		
Nearshore Ocean Water Chemistry Profiles	Profiled CTD and seawater nutrients, organic matter, & chlorophyll collected monthly at 5 reefs	2001
Moored Hydrography and Currents	Near continuous measurements of conductivity, temperature, & currents (ADCP) at 4 reefs	2001
Temperatures	Bottom temperature every 15 min at 11 reefs	2001
Irradiance	Bottom and surface irradiance every minute at 4 reefs	
Kelp Forest Ecology		
Kelp forest Community Structure	Annual data on the abundance (density or % cover), species composition and size structure of fishes, macroinvertebrates, giant kelp and understory algae at 11 reef sites	2000
Long-term Kelp Removal Experiment	Twice per season sampling (every 6 weeks) in kelp-removal and kelp-control plots at 4 reef sites. Sampled variables include: the abundance, species composition and size structure of fish, macroinvertebrates, and macroalgae, standing and detrital biomass of macroalgae.	2008
Kelp Net Primary Production	Monthly data on standing biomass, stoichiometry and biomass loss rates of giant kelp. Seasonal data on giant kelp NPP.	2002
Sandy Beach Ecology		
Macroalgal Wrack	Composition, cover and biomass of macroalgal wrack at 5 beaches	2008
Shorebirds	Shorebird density and species composition at 5 beaches	2008

*Other long-term data available from third parties include meteorology, ocean swell height and period, surface currents, satellite imagery (color, SST, kelp cover), and hydrology.

Research Presentations

SBC Investigators, students and postdocs gave more than 50 presenations or posters at scientific meetings, workshops and seminars in 2008-2009. A list of presentations on SBC research can be viewed at: http://sbc.lternet.edu/catalog/presentations.jsp

Information management

The primary objective of the SBC LTER IM system is to facilitate research and outreach efforts by focusing on data organization and integrity, ease of access, and long-term preservation. We maintain an open, cross-platform system that is based on Internet standards, leveraging existing systems where possible, and building new tools geared toward collaboration and integration between data collection and publication. The SBC LTER IM system is integrated with other research groups at MSI, particularly Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) and the Moorea Coral Reef LTER (MCR LTER) since these groups share several scientists and sampling protocols. SBC has been closely involved with the recent installation of an information management system for the MCR LTER (also at MSI/UCSB), and in development of scripted processing methods which are of use to several groups of local researchers. SBC is also well-represented in the activities of the LTER Information Managers Committee (IMC). Since SBC has adopted community-vetted components for its IM system, its products are well suited to deployment elsewhere in the ecological informatics community. SBC's proximity to the NCEAS ecoinformatics programming group has facilitated its early adoption of several programming tools, and in the process SBC has provided valuable feedback for further development of products such as Metacat, Morpho and the EML data manager library

LTER Network and Synergistic Activities

As a lead PI Reed serves on the LTER Science Council. He is also member of the LTER Executive Board, the Publications Committee, and the Writing Team which produced the LTER Strategic Plan. Reed along with investigators John Melack and Brad Cardinale were members of the LTER Network Planning Committee and active in the LTER Network's Planning Grant process. Investigator Libe Washburn serves on the LTER Network Information Systems Advisory Committee (NISAC). SBC Information Manager Margaret O'Brien is extremely active in the LTER Network 's information management arena. She serves on the Executive committee of the LTER Network's IM committee. She is currently involved in several network groups charged with: (1) developing standards for data quality control, (2) establishing a collection of vetted measurement units, and (3) evaluating the usefulness of keyword thesauri for browsing and querying metadata. She is editor of the metadata section of the IMC website, which facilitates content, recommendations and discussions regarding metadata standards and implementation. With another information manager (Corinna Gries, CAP) she led an IMC group in developing a database for managing project descriptions using the EML schema with content delivered via web services. Beyond the LTER Network, she is a member of the EML Project Committee, a national-level informatics group that oversees the development of the EML schema, and acted as the coordinator for the recent release of EML 2.1.0. She participated in a 2008 workshop at UCSB that produced a report to NASA recommending measurement and data requirements for coastal habitat monitoring. She is a co-principal investigator (with researchers at NCEAS) on a NSF funded project (Award ID 0743429) aimed at developing tools to add semantic annotation to EML metadata for SBC and network synthesis projects.

Research Findings

Below we summarize our major research findings in the three general thematic areas upon which our current award is structured. We note that much additional research not reported below has been and continues to be done with support from the Santa Barbara Coastal LTER. A full list of SBC LTER's publications and products can be found at: http://sbc.lternet.edu/catalog/publications.jsp

THEME 1: The influence of abiotic press and pulse drivers on rates of delivery of N and C to giant kelp forests

Oceanic transport of offshore shelf C and N to the inner shelf

To understand the effects of the important abiotic processes of ocean circulation and transport on the delivery of C and N to kelp forests, a broad range of oceanographic sampling has been conducted since the beginning of the SBC-LTER. The main elements of the sampling are monthly small boat surveys, an array of moorings along the inner shelf in the Santa Barbara Channel, high frequency (HF) radars for measuring surface currents (Beckanbach and Washburn 2004), and a series of oceanographic cruises onboard UNOLS vessels during 2001-2006. Results from the analysis of the oceanographic data bear directly on the Questions 1a and 1b of Theme 1.

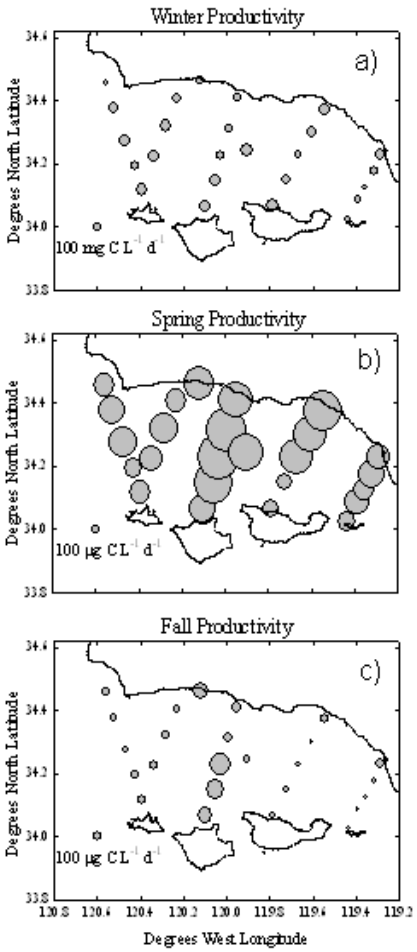


Figure 3. Phytoplankton primary productivity averaged by season. Dot size indicates productivity according to scale at lower left.

A major research focus during the first half of our current award has been the analysis and synthesis of the extensive data set from the oceanographic cruises. To date, our analyses of these cruise data have concentrated on issues related to Question 2 of Theme 1 by examining offshore oceanic sources of dissolved and particulate organic matter. In particular, we are studying the relationship between chlorophyll biomass and phytoplankton primary productivity (PPP) and the pulse drivers of wind-driven upwelling, seasonal river runoff, eddy circulation, and water mass variability. Satellite remote sensing imagery (e.g. Otero and Siegel, 2004) suggests that two areas of the Santa Barbara Channel exhibit consistently high levels of chlorophyll biomass, the western channel over the Santa Barbara Basin and the eastern channel along the mainland coast near the mouths of the Ventura and Santa Clara Rivers (Figure 2). Prevailing coastal circulation patterns place these regions of high chlorophyll biomass upstream from extensive kelp forests along the mainland coast because: (a) offshore currents are counter-clockwise and tend to transport materials from the western channel toward the mainland shore in the central portion of the channel, and (b) nearshore currents along the mainland coast are predominantly westward. Therefore we hypothesize that these areas are important sources of organic particles for kelp forests along the mainland coast where core SBC-LTER monitoring sites are located. An important goal of our cruise analyses has been to quantify patterns of PPP and chlorophyll biomass measured in situ with patterns inferred from remote sensing.

Patterns of PPP during 15 UNOLS cruises show a seasonal cycle in the Santa Barbara Channel much as is observed in terrestrial systems with high productivity in spring and lower productivity in fall and winter (Figure 3). The first empirical orthogonal function (EOF) mode derived from the PPP measurements was nearly spatially uniform and accounted for 67% of total variance. Correlation of this mode with nitrate concentrations indicates it describes wind-driven upwelling effects. The second EOF mode accounting for 17% of variance exhibited a productivity maximum in the center of the channel. The signature of this mode is evident along the central lines during spring and fall (Figures 3a and 3b). Comparison with current patterns observed by shipboard current profilers and shore-based HF radar indicates this mode is large when organized cyclonic circulation prevails in the western channel and small when it does not. It also is consistent with previous remote sensing observations of a chlorophyll maximum in the western portion of the channel. We are currently exploring which aspects of the cyclonic circulation enhance PPP; two leading contenders are increased residence time and local supply of nutrients by uplift of density surfaces.

Analysis of our UNOLS cruise data during the second half of our current award will continue to focus on Theme 1 as we will examine ocean transport processes that deliver N and C from the regions of high PPP identified in our current analysis to kelp forests near shore. This research will involve all SBC LTER oceanographic data sets including the UNOLS cruises, and nearshore monthly water sampling and moorings. Another direction that we are planning is a study of the effects of the important press driver El Niño. As of this writing an El Niño is developing in the western Pacific which, if it continues to build, will give us the opportunity to measure its effects throughout the SBC LTER study area, including the coastal ocean. In preparation, we are discussing with NSF program managers and ship operations personnel the possibility of an oceanographic cruise for late summer or fall 2010. A third research direction that we are planning involves continuous oceanographic sampling using the new technology of gliders. We currently have NSF supplemental funding to purchase one glider and are working on proposals (e.g. NOAA) to purchase a second and to fund the required technical support personnel. Data from gliders will allow continuous observation of evolving ocean conditions that will enhance our previous research on the formation of algal blooms (Anderson et al, 2006, 2008) and coastal eddies (Bassin et al. 2005) as well as facilitate our future planned research on storm driven runoff effects. Partnerships are also being explored to understand consequences of newly identified press drivers such as ocean acidification and declining oxygen levels in the northeastern Pacific. Some of this work has already begun: For example, key measurements of the coastal ocean carbonate cycle been added to the monthly cross-channel sampling of co-PI Siegel's long-term NASA funded Plumes and Blooms project.

Inner shelf transport and the sources and fates of DOM

The continental shelf in the Santa Barbara Channel is extremely narrow being only a few kilometers wide in many areas. Cross shelf processes have a dramatic effect on the supply and export of key resources to and from the kelp forest ecosystem. The nutrients sequestered in organic matter (OM) are of particular interest because of their ecological and biogeochemical significance. Organic matter (OM) is partitioned into particulate (POM) and dissolved (DOM) phases and is produced by photoautotrophic processes (phytoplankton and macroalgae). The portion partitioned into DOM serves as a substrate for heterotrophic microbial processes, and factors that control the production and remineralization of DOM can have a profound influence on the distribution of nutrients within marine systems. Despite its proximity to the coast and relatively high levels of phytoplankton productivity (> 2 g C m^{-2} d^{-1}) we observed DOM concentrations in the center of the Santa Barbara Channel to be less than or equal to concentrations measured in the subtropical oligotrophic gyre at the same latitude. This relatively low background

concentration of DOM allows us to resolve relatively small changes in this important organic pool.

Our preliminary observations of a cross-shelf survey of the Santa Barbara Channel revealed a significant onshore to off shore gradient in the concentration of DOM indicating the build up of a pool of organic nutrients that could potentially be available for export away from the near shore system. Significant heterogeneity in DOM concentrations was observed throughout the Channel (Figure 4). DOC sources, sinks and dilution processes of this upwelling system control much of this variability in DOC concentrations.

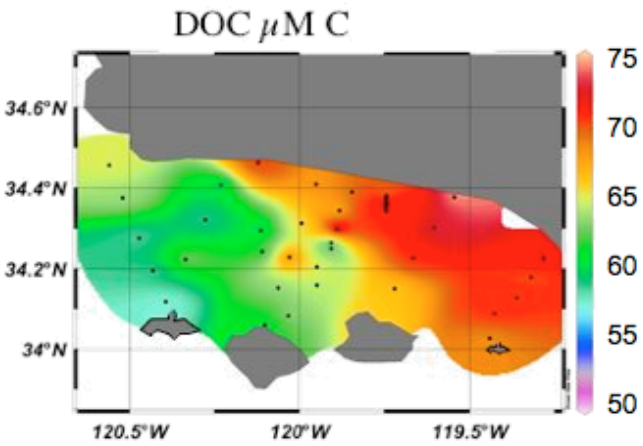


Figure 4. Surface contour of DOC in the Santa Barbara Channel October 2005. Note DOC gradient that develops from onshore to off shore in the western portion of the SB Channel.

Biogeochemically, the portion of newly produced DOM that is resistant to rapid microbial degradation is potentially available for export away from the shallow near shore environment. However, in order for DOM to be important in cross shelf transport a gradient must develop between the near shore and offshore environments. Knowledge of the sources and fate of the DOC produced in these upwelled water masses is needed to gain insight into the bioavailability of this important organic pool. However, prior to our investigations little was known about the temporal evolution of this gradient, its persistence or how it developed in the context of primary productivity and potential availability to heterotrophic microbes.

In January 2008 we initiated a cross shelf time series study to investigate the temporal and spatial gradients of particulate and dissolved organic matter and their potential sources and sinks in the near shore environment. Monthly measurements of POM, DOM, macro nutrient concentrations, biomass, productivity and community structure of phytoplankton and bacterioplankton communities were collected for 16 consecutive months from 4 depths at 5 stations that spanned from the Mohawk kelp forest to 3 km offshore. Preliminary analysis of these data show significant temporal variability in cross shelf transport that causes the kelp forest ecosystem to be at times highly isolated from offshore influences to it being strongly influenced by offshore waters. The horizontal transect from the Mohawk kelp forest illustrates seasonal gradients of organic and inorganic nutrients between the shallow rocky reef and deeper offshore ocean (Figure 5a). During periods of upwelling large pulses of inorganic nutrients were introduced into the near shore and offshore environments (Figure 5a) resulting in a phytoplankton bloom in early spring across the 3 km transect (Figure 5b). As upwelling relaxed and inorganic nutrients were drawn down temporal gradients in POM and DOM developed, reaching maxima by late spring/early summer (Figure 5ac&d). A pronounced spatial gradient in POM and DOM was observed with maxima developing closest to the kelp forest. In order for DOM and POM to accumulate in the near shore zone biological production and consumption processes must be uncoupled and the rate of physical dispersion must be less than net organic matter (OM) production. Thus, the accumulation of OM in the nearshore environment suggests that the connectivity between kelp forests and the offshore ocean is reduced during periods when upwelling is relaxed and kelp forests become relatively isolated from offshore waters. The source, quality and bioavailability of the resulting OM can have important implications for nutrient cycling within the kelp forest. For example, if the DOM that accumulates nearshore is resistant to rapid microbial degradation, then the nutrients sequestered in DOM and POM are potentially

available for export away from the near shore system. These results demonstrate the development of gradients in OM: Additional microbial bioassays were also conducted throughout the study to assess the bioavailability of the accumulated DOM. Analyses of these data are ongoing and should provide further insight into the fate of the accumulated OM and its potential for export from the nearshore environment.

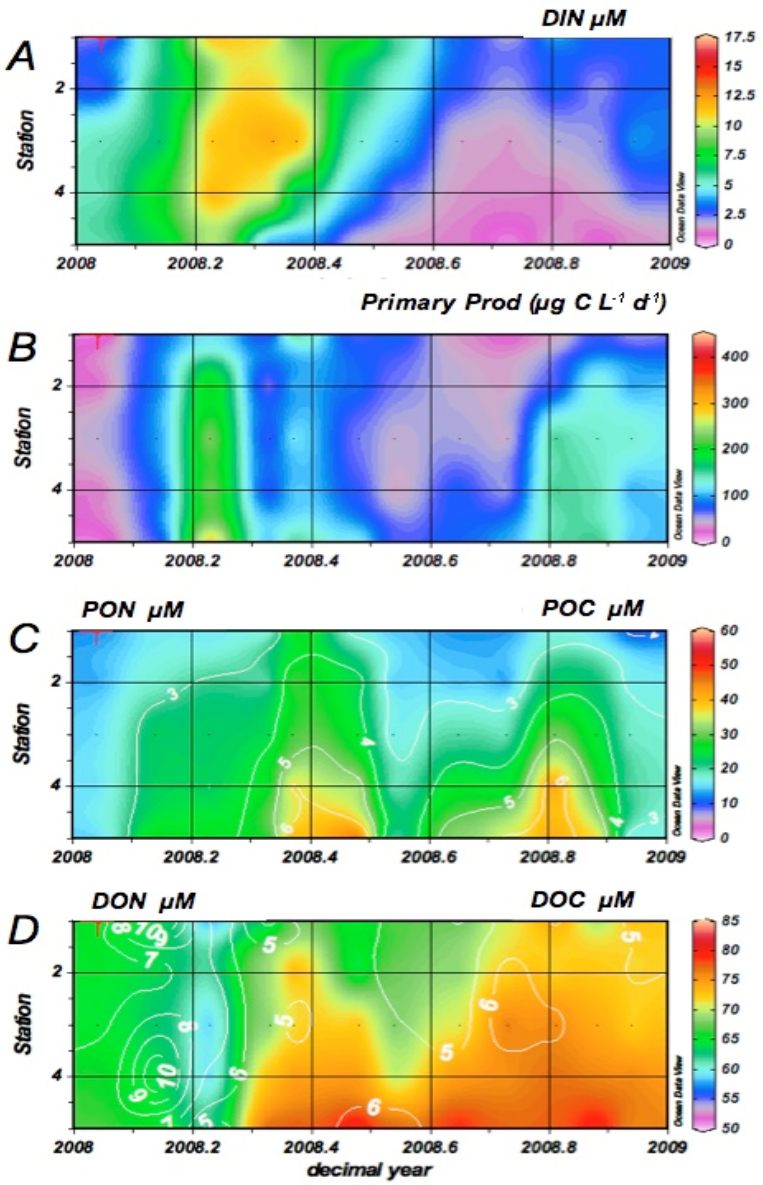


Figure 5. Surface contours of integrated and depth normalized measures of A) inorganic nitrogen; B) phytoplankton primary production, C) POC and PON (overlay contour); D) DOC and DON (overlay contour) collected during 2008 from the rocky reef (station 5) to 3 km into the SBC (station 1).

<u>Watershed processes & land subsidies to kelp forests</u>

Empirical studies: Seventy-four catchments, with a total area of 790 km^2 (ranging from 1 to 50 km^2), drain from the Santa Ynez Mountains along the northern coast of Santa Barbara Channel to coastal waters that support kelp forest ecosystems. These coastal catchments have mountainous headwaters and sloping coastal plains separated by transitional foothills. From west to east, there are both elevational and land use gradients. Headwater elevations increase from approximately 300 to 1400 m, and land uses on the coastal plain and foothills change from mostly rangeland to a combination of urban and agricultural land with chaparral in the mountains.

A network of rain gauges and water level recorders have been installed to permit calculation of rainfall and runoff for a representative set of coastal watersheds (Figure 6). Intensive sampling during rainfall events and weekly to bi-weekly collections during periods with baseflow are routinely performed in the instrumented watersheds. Water

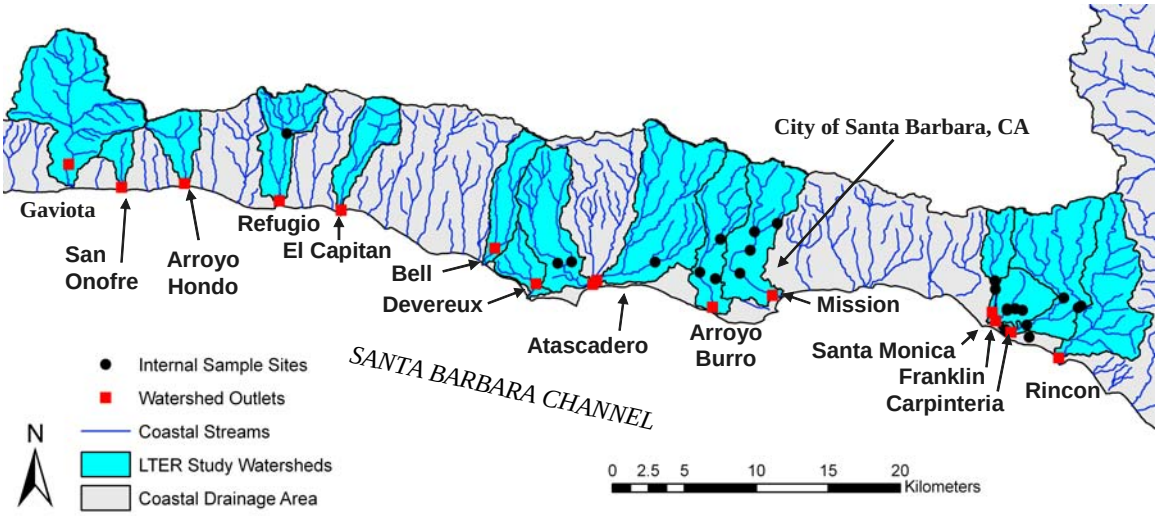


Figure 6. Catchments along Santa Barbara Channel with LTER stream gauging and sampling stations (red squares indicate stations near mouth; black dots indicate stations within catchments).

samples from streams are analyzed for (a) nitrate, ammonium, total dissolved nitrogen, and particulate nitrogen; (b) soluble reactive phosphorus, total dissolved phosphorus and particulate phosphorus; (c) particulate organic carbon; (d) total suspended sediments; and (e) conductivity. Subsets of samples are analyzed for silica, major cations and anions, and the natural abundances of ^{15}N and ^{13}C.

Most of the annual precipitation and corresponding runoff occurs in only a few large events resulting in high peak discharges and a rapid return to near baseflow conditions. Consequently, a major proportion of the annual fluxes occurs during a few large storms in each year. For example, in water year (WY) 2003, 46%, 28% and 40% of the respective nitrate, phosphate and dissolved organic nitrogen fluxes were exported during the largest event. We found that land use greatly affected nutrient export from coastal watersheds. Descending order of concentration and flux of nitrate and dissolved organic nitrogen usually followed descending intensity of land use. Volume-weighted mean concentrations of nitrate generally range from 5 to 25 µmol L^{-1} in undeveloped areas, increase to about 100 µmol L^{-1} for urban and most agricultural catchments, and are in excess of 1000 µmol L^{-1} in catchments with greenhouse-based agriculture. Comparative values for dissolved organic nitrogen are 10 to 25 µmol L^{-1} for undeveloped, 60 to 100 µmol L^{-1} for urban and agricultural, and about 200 µmol L^{-1} for greenhouse-based agriculture. Differences in phosphate concentrations were observed between intensive agriculture and urban or less intensive agricultural usage, and between urban and undeveloped catchments. To refine our whole catchment analyses we examined nutrient loading at the landscape-unit scale (Robinson et al. 2002, 2005a, b; Robinson 2006). Two intensive agricultural land uses (greenhouses and nurseries) were, in general, higher than two urban classes (commercial and residential), which were higher than chaparral areas. Using an urban growth model to forecast land uses 50 years into the future and estimates of nutrient export for different land uses, we found that the forecasted reduction in agricultural land use and expansion of urban development leads to a decrease in nitrate export and an increase in phosphate export. Goodman (2008) includes export from the largely suburban catchment of Devereux Slough, which has the added complication that the slough is open to the ocean only occasionally.

The large variation in the concentration of nutrients in runoff during storms requires the sampling of nutrient export at a time step significantly less than one day (Melack and Leydecker 2005). For example, nitrate, soluble reactive phosphate and particulate organic nitrogen varied with the hydrograph: soluble reactive phosphate varied in phase with outflow, nitrate exhibited the opposite pattern, and particulate organic nitrogen concentrations, along with other particulates, reached a maximum on the rising limb of the first storm pulse, implying different mechanisms and/or sources for the various species.

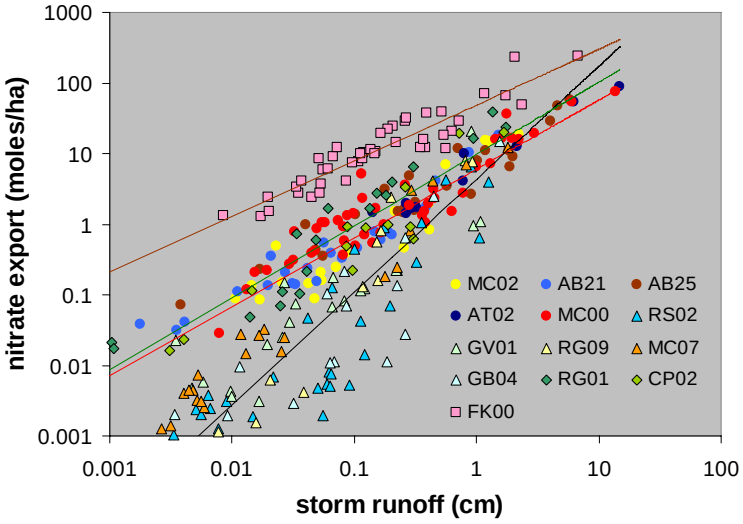


Figure 7. Nitrate exported per storm, expressed as moles ha^{-1}, and runoff per storm, expressed as cm per unit area, for the period from 2001 to 2005. Codes to creek names are as follows: MC, Mission; AB, Arroyo Burro; AT, Atascadero; RS, Rattlesnake; GV, Gaviota; RG, Refugio; CP, Carpinteria; FK, Franklin. Numbers after creek codes refer to position in catchment. Symbols indicate predominant land use in catchment as follows: ▲, undeveloped uplands; ●, suburban/urban; ◊, agriculture; ■, intensive agriculture.

Figure 7 provides a synthesis of the relationship between nitrate exported per storm, expressed as moles ha^{-1}, and runoff per storm, expressed as cm per unit area, for the period from 2001 to 2005. Urban and agricultural land uses generate about the same export when agricultural use is10% or less. An especially interesting feature is the steep slope of nitrate export from undeveloped catchments. As long as storm size remains small, nitrate export from undeveloped areas is small (i.e., 10-100 times lower than from urban catchments). As storm size increases, there is a disproportional increase in export, and flux from these areas exceeds that contributed from urbanized or agricultural zones when storm runoff exceeds 2 to 5 cm per unit area.

To investigate the relative importance of marine and terrestrial sources of organic matter to the consumers in nearshore kelp reefs we measured stable isotopes of C and N in suspended organic matter and different types of consumers over a 4 year period in 4 nearshore areas with varying exposure to terrestrial runoff (Page et al. 2008). $\delta^{13}C$ values of suspended particulate organic matter on reefs tended to decrease following periods of significant rainfall at reefs most influenced by runoff. A pattern of ^{15}N-enrichment in 2 common benthic feeding species, the sea urchin *Strongylocentrotus purpuratus* and the annelid *Diopatra ornaata*, with increasing influence of runoff indicated that terrestrially-derived N may enter the food web indirectly through microbes or algae.

Fires impact the hydrology and suspended sediment and nutrient export. Stream gauging and intensive storm runoff and baseflow sampling were used to determine impacts from a fire that burned 3,011 ha in coastal watersheds near Gaviota bordering the Santa Barbara Channel in June 2004 (Coombs 2006). Burned watersheds showed order of magnitude increases in peak discharge, and suspended sediment export from burned watersheds was approximately 10 times greater than from unburned watersheds. Ammonium export from burned watersheds primarily occurred during the first 3 storms of the water year and was 32 times greater than in unburned upland watersheds. Nitrate, dissolved organic nitrogen, and phosphate export from burned watersheds increased by 5.5, 2.8, and 2.2 times, respectively, compared to unburned chaparral watersheds.

From July 2008 to June 2009, three major fires occurred in the foothills and mountains above the greater Santa Barbara area, all within the area being studied by the Santa Barbara Coastal LTER program. As the rainy season is approaching, we are planning to compare the influence of fire timing (autumn versus spring versus no fire) and fire severity on a variety of ecological and environmental responses. Measurements and modeling of stream discharge and the export of sediment and nutrients will be used to integrate watershed responses to fire and to link upslope disturbances, stream ecosystems, and nearshore marine environments. Soil movement and landslides will be measured at selected sites and synoptically with airborne LiDAR. Regrowth of vegetation will be determined at the watershed- scale using high resolution remote sensing and at the transect-scale by direct measurements of re-sprouting plants and ground cover. We will evaluate the production and consumption of NO_3^- in burned and unburned areas after the fires, before vegetation fully re-establishes, through measurements of nutrient concentrations and fluxes, measure N processing by microbes, and link N losses to hydrological processes.

Modeling studies: We have developed a hydrological model that predicts runoff from rainfall to extend our measurements of stream discharge and nutrients to all coastal watersheds entering the Santa Barbara Channel within our primary 790 km^2 study area (Beighley et al. 2003, 2005). Furthermore, we have used our rainfall-runoff model to explore the impacts of watershed characteristics, transient weather regimes and land conversion on the frequency distributions of runoff events and their influence on nearshore waters (Beighley et al. 2008). Based on historical evidence and projected urbanization, a 600% increase in runoff during storms from the coastal plain was calculated to occur from 1929 to 2050, which shifts the dominant source of runoff from the mountains to the coastal plain. By combining drainage areas, export relationships, runoff frequencies, nearshore water volume, ambient nitrate and phosphate concentrations in nearshore waters and an assumed mixing volume, we modeled the probability of a runoff event resulting in a particular nearshore nitrate or phosphate concentration. For example, the frequency of a storm event that produces runoff $\geq$ 2.5 cm and a nearshore nitrate concentration greater than 12 $\mu mol\ L^{-1}$ ranges from 3% in non-El Nino years to 20% in El Nino years.

Regression models have been developed to estimate the flux (mol ha^{-1}) for a given storm based on the percentage of catchment area used for agriculture or classified as impervious surface, the estimated discharge during the storm and the cumulative water year discharge at the end of the storm. Daily models were also developed to estimate the daily flux (mol $ha^{-1}\ d^{-1}$) using daily flow and the cumulative water year discharge at the end of the given day.

To extend our modeling to include mechanistic aspects of the water balance and N and C dynamics, we have begun to apply the Regional HydroEcological Simulation System (RHESSys). Initial work has focused on the effect of uncertainty in water and climate inputs on streamflow and evapotranspiration (ET) outputs in the Mission Creek catchment. We have tested model sensitivity to three sources of input uncertainty: spatial scaling of precipitation, non-linear variations in temperature caused by a marine fog layer, and outdoor water use. Results indicate that the model is most sensitive to uncertainty in soil parameters and precipitation inputs. Sensitivity to temperature variations resulting from a marine fog layer was negligible in terms of total water flux, but significant variations in ET and streamflow at the seasonal level were observed. Likewise, model sensitivity to outdoor water use was relatively small except potentially during the summer months. Future research in the Mission Creek catchment will be focused on quantifying the effect of fine scale urban spatial complexity and impervious surface connectivity on hydrologic and biogeochemical processes and appropriate modifications of RHESSys model will be developed. The model will then be used in conjunction with land use and climate change forecasts for the region with a goal of quantifying potential catchment responses to different environmental change scenarios.

C inputs to kelp forests identified by stable isotopes.

Understanding trophic connections and how resource variability affects consumers is necessary to predict how food webs might shift in the face of environmental change. Macroalgae and phytoplankton support highly productive marine ecosystems. Research based on stable isotope analyses has supported the idea that macroalgal detritus, especially that of the giant kelp *Macrocystis,* is a major source of dietary carbon to benthic suspension-feeders. However, our recent findings from a four-year stable isotope study (Page et al. 2008) suggest that phytoplankton, not kelp, are the main food resource for benthic suspension-feeders on reefs in the Santa Barbara Channel, and that variation in phytoplankton abundance, combined with feeding selectivity and the scale of consumer tissue turnover times, may drive variability in consumer isotope values.

A common assumption made in 'snapshot' isotope studies of coastal ecosystems over the past 20 years is that the isotopic signature of coastal phytoplankton is similar to that of offshore phytoplankton. Our results suggest that this important supposition may be incorrect. Typically this assumption is made because of the difficulty in separating phytoplankton from detritus to obtain an uncontaminated isotope signature, also a problem encountered in freshwater systems. We are developing methods to overcome these problems and address fundamental questions about the role of POM in coastal food webs. Our objectives are to: 1) determine the contribution of phytoplankton and giant kelp detritus to the pool of suspended reef POM and whether POM composition varies with distance from kelp forests, and 2) evaluate how different components of the POM are used as food by reef suspension feeders.

Associate Investigator Page and post-doc Miller are exploring the contribution of phytoplankton and kelp detritus to POM in coastal waters using two complementary approaches: (1) an advanced flow cytometry and cell-sorting system to separate phytoplankton from bulk POM, and (2) analyses of essential polyunsaturated fatty acids (PUFA) in POM and consumers. They have obtained preliminary data that demonstrate the feasibility of both of these methods (Figure 8), and have submitted an NSF proposal for support of expanded work on these issues. Isotope values of isolated inshore phytoplankton and kelp, and compound-specific PUFA, will be used in mixing models to estimate relative contributions of these two major primary producers to suspension feeder diets. They will also test two hypothesized mechanisms influencing isotopic composition of consumers: (1) selective feeding on particular fractions of the POM, and (2) tissue turnover times.

Results from this work should provide new insights into the trophic support of benthic suspension feeders, an ecologically and economically important guild in coastal

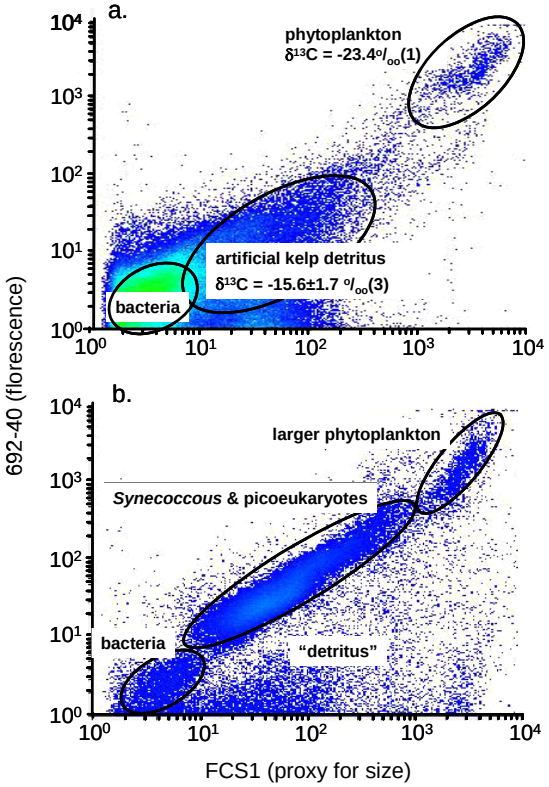


Figure 8. (a) Illustration of the separation of particle classes of natural suspended POM based on size and florescence using the Influx Mariner flow cytometer. Particle classes can be "gated" by optical properties and sorted for isotopic analysis. (b) Separation of laboratory cultured phytoplankton from kelp (*Macrocystis pyrifera*) detritus generated in the laboratory based on optical properties.

ecosystems. This research will test the general hypothesis that giant kelp detritus is an important source of dietary carbon to suspension feeders, a commonly accepted idea that needs re-evaluation in light of key assumptions that have been made in its support. Stable isotope analyses are an ideal tool for testing this hypothesis given the spatial and temporal scales of variability that exist in the abundance of phytoplankton and giant kelp at our study sites. Our anticipated sampling scheme combined with time-series data on producer biomass collected as part of our long-term core monitoring (Table 1) will enable us to capture this variability, which is generally missed by short-term food web studies involving stable isotope analyses.

Timing and magnitude of nitrogen delivery to giant kelp forests from different sources

We examined sources of nutrients to the kelp forests of the Santa Barbara Channel using time series obtained from an *in situ* nitrate autoanalyzer moored at three of our long-term study sites (Carpinteria, Naples, Arroyo Quemado). The data obtained from this effort provided the first high-resolution (every 30 minutes) time series of nitrate + nitrite (dissolved inorganic nitrogen, DIN) concentrations for this environment. These measurements showed that the major mechanisms that supplied DIN to the inner shelf of the Santa Barbara Channel varied seasonally and consisted of upwelling, diurnal internal tides, and storm runoff (McPhee-Shaw et al. 2007). Upwelling dominated increases of inner-shelf DIN between March and May and accounted for more than half of the annual advective DIN transport to shallow reefs where kelp forests occur (Table 2). In summer, internal waves provided an important source of DIN because they occurred when surface nutrient concentrations were depleted and the other supply mechanisms were inactive. Brief episodes of upwelling became important in late autumn and early winter. DIN inputs from storm runoff, detected as salinity dilution at the moorings and estimated from measurements of stream discharge and nutrient concentration were significant during winter runoff events.

		Contribution to annual DIN supply			
		With dilution estimates		With hydrologic estimates	
Mechanisms for nutrient delivery	Days	Low end-member stream DIN (%)	High end-member stream DIN (%)	Greater ocean volume (%)	Smaller ocean volume (%)
Year 1: 01 Mar 2001–28 Feb 2002					
Spring upwelling	39	70	68	63	47
Summer internal waves	54	15	15	14	10
Winter upwelling	13	12	12	11	8
Terrestrial storm runoff	6/37*	2	4	12	35
Year 2: 01 Mar 2002–28 Feb 2003					
Spring upwelling	65	81	77	79	70
Summer internal waves	48	9	9	9	8
Winter upwelling	11	7	7	7	6
Terrestrial storm runoff	13/22*	2	7%	4	15

* Days are identified using the moored salinity time series and the hydrographic methods (see text for details).

Table 2. Annual contribution for two sequential years of DIN supplied by four primary mechanisms that advect nitrate into the inner shelf of the Santa Barbara Channel.

Building on this work we sought to determine the relative importance of different sources of nitrate to the annual nitrogen needs of the giant kelp *Macrocystis pyrifera.* We did this by measuring ambient nitrate concentrations in the kelp forest at the Mohawk Reef kelp for 13 months (using the moored nitrate autoanalyzer described above) and characterizing nitrate delivery using water column thermal structure and flow data collected in the forest interior and at its offshore edge (Fram et al. 2008). Rates of net nitrogen uptake by kelp were calculated for the entire forest (using data collected from our long-term studies of kelp net primary production; Table 1 and Theme 2 below), and for a select subset of kelp fronds to isolate vertical and cross-shore differences in nitrogen acquisition. The forest's monthly nitrate supply varied by a factor of 50, while measured

net nitrogen acquisition varied only fivefold regardless of the method used to measure it. Maximum net nitrogen acquisition rates for fronds in the forest interior were 0.18 mmol N g^{-1} $month^{-1}$ during spring upwelling and declined fourfold during autumn until upwelling resumed the following year. Modeled gross nitrogen uptake with consideration of Michaelis–Menten kinetics for nitrate and mass transfer limitation was higher than observed net acquisition except during the warm stratified summer and autumn months, when net acquisition exceeded modeled gross uptake (Figure 9). This shortfall indicates that the kelp forest received over half its nitrogen from sources other than nitrate (such as ammonium from epibionts) during this period. Most of the nitrate in the forest was delivered as a result of upwelling-favorable winds and convection. Internal waves and local streams contributed, 9% of the nitrate delivered to the forest on an annual basis and 20% during stratified periods. Kelp used less than 5% of the nitrate supplied to the forest. Nitrate delivery to this modest sized kelp forest was roughly equivalent between alongshore (45%) and cross-shore flows (55%), which distinguishes it from large kelp forests in which cross-shore flows dominate exchange.

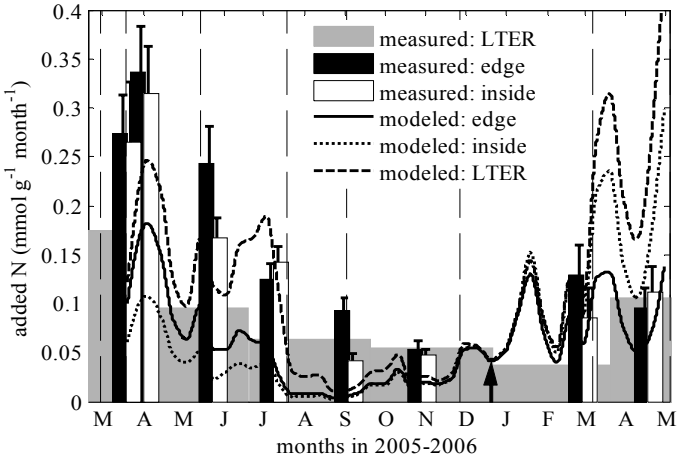


Figure 9. Time series of measured acquisition and modeled uptake of nitrogen in mmol (wet g) $^{-1}$ $month^{-1}$ by growing canopy fronds at the edge and inside the Mohawk kelp forest, and of all fronds in a 40 m x 40 m area of the interior of the forest (LTER) for the period 21 March 2005 through 30 April 2006.

<u>Carbon and nitrogen linkages between giant kelp forests and sandy beaches</u>

Wave-exposed sandy beaches represent a classic example of a subsidized sedimentary ecosystem where *in situ* primary production is very low and biotic communities are primarily supported by imported organic material from other ecosystems. Subsidies of drift macroalgae or wrack exported from kelp forests to beaches in the Santa Barbara Channel can exceed 500 kg m^{-1} y^{-1} for *Macrocystis pyrifera* alone (Dugan et al. *in review*). These inputs from kelp forests to beaches exhibit strong temporal variation in response to pulse and press drivers, such as seasonal variation in wave climate, sediment supply and ENSO events, as well as kelp forest condition (Revell et al *in press*).

Our ongoing investigations of the role of kelp wrack subsidies in beach ecosystems indicate that they support a substantial component of the beach food web. Spatial variation in wrack

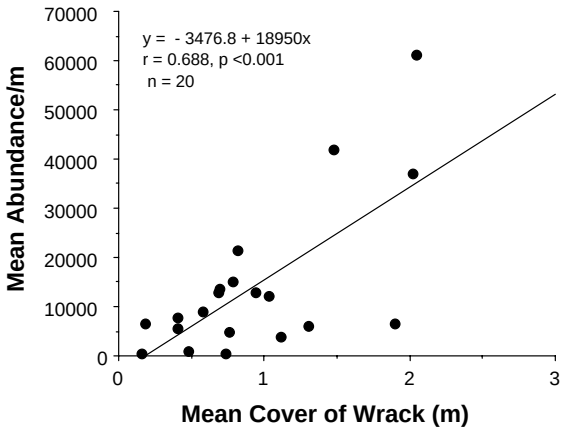


Figure 10. Relationship between the biomass of kelp wrack and the abundance of talitrid amphipods.

abundance propagates up through invertebrate detritivores (Figure 10) to predatory shorebirds, including the Western snowy plover, a threatened shorebird that breeds on beaches (Dugan et al 2003). Temporal variation in the supply of kelp wrack to beaches in response to press and pulse drivers is expected to have important consequences to the beach food web. For example, we found a doubling of invertebrate consumer richness in 8 weeks following weekly additions of fresh *Macrocystis* to a one of our beach study sites. Consumption of kelp wrack can be rapid as talitrid amphipods alone were estimated to consume kelp wrack at a rate of 18 kg m^{-1} of shoreline in one month, which constituted about ~40% of the measured input (Lastra et al 2008).

This rapid processing of macroalgal wrack by invertebrate detritivores and its decomposition and subsequent nitrogen mineralization by bacteria can lead to high concentrations of dissolved nitrogen in intertidal porewater (>1000 uM, Figure 11), particularly on beaches with heavy wrack accumulation (Dugan et al *in review*). Highest DIN concentrations (>200 uM) in intertidal porewater were found in late summer and fall when sand accumulation on Santa Barbara beaches is greatest. Much lower DIN values (<100 uM) occurred in winter and spring when sand levels are typically low. The interaction of press and pulse drivers such as tidal forcing/drainage, erosive events and sediment dynamics are expected to strongly affect release and transport of dissolved nutrients from beach aquifers, as will interactions with terrestrial groundwater sources when present. Planned studies of the decomposition and mineralization of kelp wrack, and the timing and magnitude of the release of intertidal porewater will be used to evaluate the significance of this potential nitrogen source to coastal waters and kelp forests.

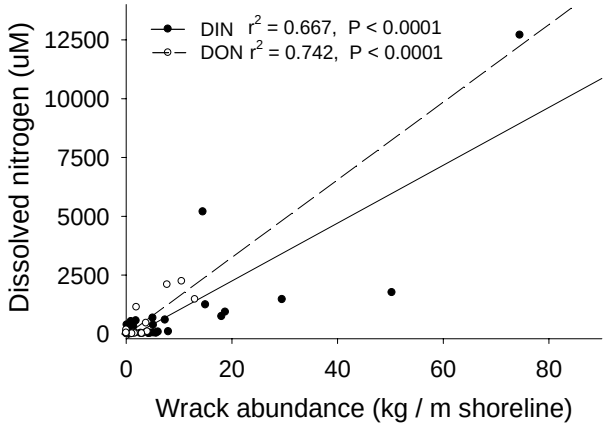


Figure 11. Relationships between the biomass of macroalgal wrack and dissolved inorganic nitrogen and dissolved organic nitrogen in beach pore water

Our ongoing research in this area seeks to understand how beaches function as both filters and sources of regenerated nutrients to the coastal ocean. Similar to wetlands and estuaries, beaches may act as a filters or buffers for anthropogenic nutrient loads conveyed in groundwater flowing from land to the ocean. As indicated above, the beach ecosystem may also represent a nutrient source to coastal ocean primary production as wave and tidal activity circulates organic materials, such as wrack and phytoplankton, through beach sand where they are decomposed and mineralized. The dynamics of release and the transport rates of these dissolved nutrients from the shallow unconfined aquifers of sandy beaches to the nearshore ocean will be studied using an array of temporary multi-level sampling wells and benchmark referenced piezometers or pressure transducers (depending on tidal height) at two beach sites that differ in freshwater influence through a single spring and single a neap tide cycle. Calculations of water circulation through the beach sediments will be made using Darcy's Equation (D (discharge) = K (hydraulic conductivity) x A (area) x dh/dl (slope of water surface)). Wells will be sampled frequently for a selection of water chemistry and biogeochemical parameters over the tidal cycle.

The ability of beach ecosystems to accumulate and process wrack material can be significantly affected by abiotic press and pulse drivers that interact with human activities (Schlacher et al 2007). Our finding of a significant relationship between wrack abundance and dry beach width (Revell et al *in press*), suggests that when dryer upper

beach zones are narrow or absent, wrack accumulation and its availability to beach consumers is decreased. Of particular concern in this regard is climate-induced sea level rise which is expected to increase coastal erosion and reduce beach width and thereby negatively affect beach food webs. Coastal armoring, a common societal response to beach erosion is expected to expand with sea level rise. However, we found that beaches with coastal armoring were significantly narrower and had 1-3 orders of magnitude less wrack compared to adjacent unarmored beaches (Dugan et al. 2008). Shorebird use of armored sections was also significantly lower. Our studies of the effects of coastal armoring on intertidal beach communities are ongoing and should provide important insights into interactions between humans and climate change and their ecological consequences to linkages between sandy beach and kelp forest ecosystems.

THEME 2: The direct and interactive effects of key press and pulse drivers on kelp forest community structure and function

Role of disturbance and N supply on giant kelp abundance and NPP

Net primary production (NPP) is fundamental to life on earth as it influences nearly all ecosystem processes. As such, NPP constitutes a critically important ecosystem function and determining its patterns and principal environmental drivers is justifiably one of the core research areas shared by all sites in the LTER network. NPP is influenced by disturbance-driven fluctuations in foliar standing crop (FSC) and resource-driven fluctuations in rates of recruitment and growth, yet most studies of NPP have focused primarily on factors influencing growth. We have been measuring NPP, FSC, recruitment, and growth rate of the giant kelp, *Macrocystis pyrifera* at three kelp forests in the Santa Barbara Channel since May 2002 to determine the relative roles of FSC, recruitment and growth rate in contributing to variation in annual NPP (Rassweiler et al. 2008). Our results to date show that the initial FSC present at the beginning of the growth year and the recruitment of new plants during the year explained 63% and 21% of the inter-annual variation observed in NPP, respectively (Reed et al. 2008). The previous year's NPP and disturbance from waves collectively accounted for 80% of the inter-annual variation in initial FSC. No correlation was found between annual growth rate (i.e., the amount of new kelp mass produced per unit of existing kelp mass) and annual NPP (i.e. the amount of new kelp mass produced per unit area of ocean bottom), largely because annual growth rate was relatively constant compared to initial FSC and recruitment, which fluctuated greatly among years and sites. Although growth rate was a poor predictor of variation in annual NPP, it was principally responsible for the high values observed for NPP by *Macrocystis* (up to 4.4 kg dry mass m^{-2} y^{-1}). These high mean values reflected rapid growth (average of ~ 2% $^{-d}$) of a relatively small standing crop (maximum annual average = 444 g dry mass m^{-2}) that replaced itself about seven times per year. Our observations of continuously high nitrogen content in kelp (generally above 1%) coupled with our finding that growth was unrelated to the concentration of DIN in seawater at two of our three sites (Figure 12) suggests that growth has rarely been nitrogen limited since our study began.

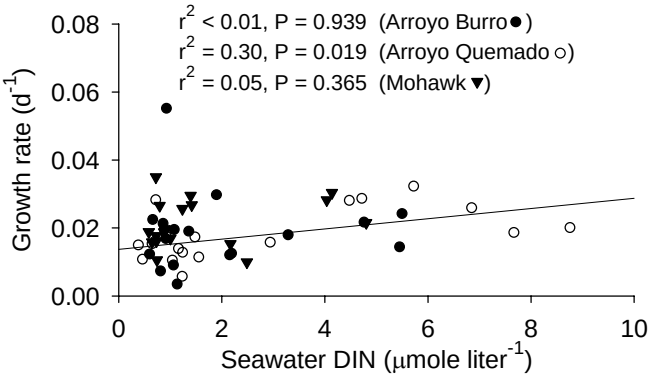


Figure 12. The relationship between specific growth rate and the ambient concentration of dissolved inorganic nitrogen (DIN).

These findings contrast with those of other investigators who studied kelp growth during prolonged conditions of nutrient stress associated with the 1982-83 El Niño, and they lend support to the contention that the importance of intra-annual variation in nitrogen supply in determining kelp growth and production depends on the state of longer-term climatic regimes.

Our time series data on biomass and NPP by giant kelp (Rassweiler et al. 2008) are unique in that we know of no other data for macroalgae that match their temporal and spatial resolution (monthly measurements ongoing since 2002 at three sites). Such resolution is needed to detect directional changes in kelp biomass and NPP associated with long-term press drivers (e.g. global climate change) in the presence of more variable fluctuations associated with short-term pulse drivers (e.g., winter storms). Unfortunately, the large effort associated with collecting data on kelp biomass and NPP limit the number of sites that we can sample, which greatly restricts our ability to place our results into a larger regional context. Motivated by this limitation we analyzed our time series data to evaluate the validity of using a common and easily measured population variable (kelp frond density) to estimate the more difficult to measure variables of standing crop and NPP We found that standing crop was strongly correlated to frond density ($r^2 = 0.79$) and that data on frond density collected in summer were particularly useful for estimating annual NPP, explaining nearly 80% of the variation in the NPP from year to year (Reed et al. 2009). Currently we are applying these relationships to annual time series data on frond density collected at 9 of our long-term monitoring sites as well as to similar data collected by investigators at sites in other regions to test our predictions concerning the role of disturbance in determining the magnitude and variability of annual kelp NPP.

Limits to the spatial extent of data that are routinely collected by divers have led us to search for additional means of investigating regional patterns in kelp biomass and NPP. With additional funding from NASA we have been exploring the use of high-resolution satellite imagery to investigate regional dynamics of giant kelp biomass and production (Figure 13). Our monthly measurements of kelp biomass and frond density in fixed plots collected by divers were strongly correlated with satellite determinations of Normalized

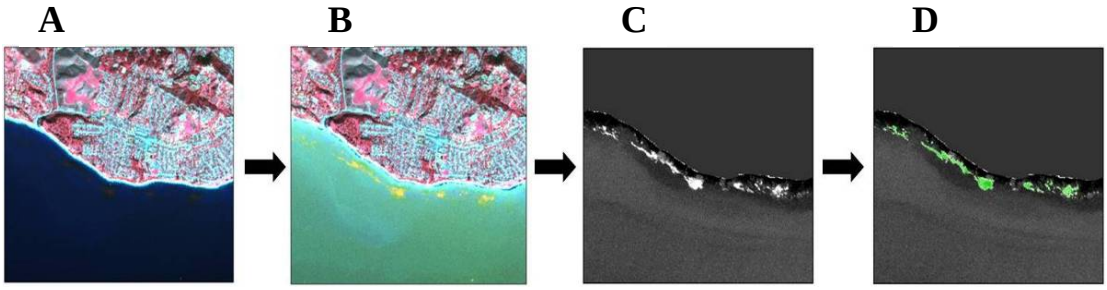


Figure 13. Four steps in the procedure for canopy cover delineation from SPOT 5 imagery. (A) False color SPOT image after geometric and atmospheric corrections have been performed (B) Resampled image after land and cloud areas have been masked out (C) PC band 2 (see Table 1 for band loadings), kelp is easily differentiated in this image because kelp's spectral signature closely matches the second mode of variability of the principal components rotation (D) PC band 2 after the threshold, manual edits, and winnowing filter have been applied. Pixels of kelp canopy are displayed in green.

Difference Vegetation Index (NDVI) signals of those plots ($r^2 = 0.77$). We are using this relationship to examine the variability of kelp biomass across multiple scales (pixel, plot, kelp bed, and region) and to explore the degree to which the relationship between plot-scale changes (as measured by divers) and bed-scale changes (as assessed remotely by satellites) vary with kelp bed location, kelp bed size and the location of plots within a kelp bed (Cavenaugh et al *in review*). By using our intensive diver measurements to parameterize satellite estimates of kelp biomass, we hope to better understand patterns

and drivers of giant kelp biomass and production across a spectrum of spatial and temporal scales.

Interactions between the forest & its flow environment and their consequences on kelp and associated biota

Pulse and press drivers that alter the biomass of giant kelp change the physical structure of the kelp forest, which can have cascading effects on fluid flow, light attenuation and the delivery of waterborne subsidies. These interactions in turn can profoundly influence the biotic structure and ecological functioning of the kelp forest community. To examine the extent to which the forest interacts with impinging currents we measured the flow characteristics inside and surrounding the kelp forest at Mohawk Reef using an array of 13 acoustic Doppler current profilers. We found that velocities were damped by as much as 60% in the interior of the forest and accelerated by as much as 200% along the forest's outer boundary as flow was shunted around the forest (Gaylord et al. 2007). We also found that the shading by the kelp canopy caused as much as a 90% reduction in fraction of surface light reaching the bottom in the interior of the forest relative to the edge of the forest (Figure 14). These physical features bear on the performance of kelp and other forest organisms that rely on light for photosynthesis and/or currents to deliver nutrients and food. For example, we found that kelp fronds on the seaward edge of the forest were longer, bushier (i.e. had larger more numerous blades per unit length) and had higher overall growth rates than fronds growing in the interior of the forest (Stewart et al. 2009). Carbon and nitrogen accumulation by edge fronds was also higher, which fueled growth rates of edge fronds that were nearly twice as high as interior fronds when the kelp canopy was densest. Thus, the growth and tissue chemistry of *M. pyrifera* within the kelp forest depended on the extent to which the kelp forest modified the physical conditions within it.

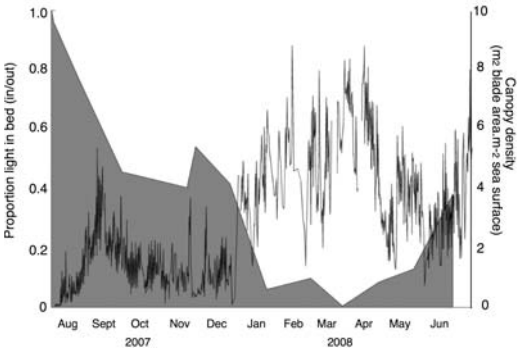


Figure 14. Ratio of bottom irradiance in the interior of the kelp forest to that outside the kelp forest. Shaded area denotes the density of the surface canopy of giant kelp

We have evidence that giant kelp similarly affects the performance of kelp forest consumers. The colonial bryozoan *Membranipora serrilamella* is a ubiquitous filter feeding invertebrate that lives on the blades of giant kelp. We have found that abundance and frequency of occurrence of *Membranipora* were as much as two orders of magnitude higher on the outside edges of forests compared to their interiors (Figure 15), due to higher rates of recruitment and growth at the forest edge (Arkema 2008). Lower

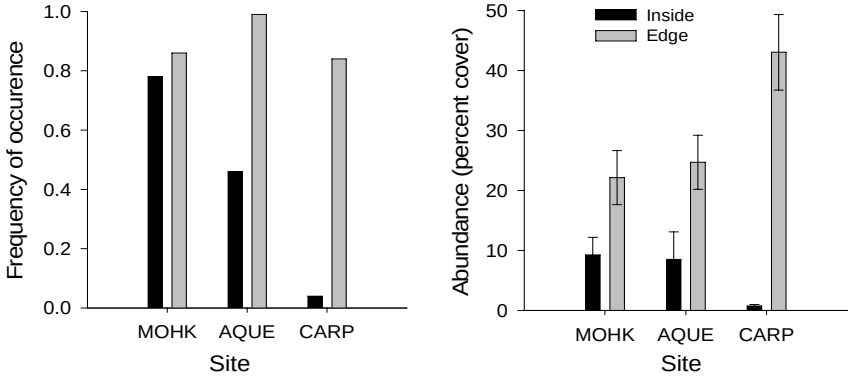


Figure 15. The frequency of occurrence and percent cover of *Membranipora* on kelp blades inside and at the outside edge of the kelp forests at Mohawk Reef (MOHK) Arroyo Quemado (AQUE) and Carpinteria Reef (CARP).

rates of recruitment and growth in interiors of forests were attributed to measured reductions in flow and particle flux caused by the presence of giant kelp. Feeding success was highest at intermediate flow speeds and *Membranipora* abundance and growth rate were greatest at sites where water moved at intermediate flow speeds the majority of the time (Arkema 2009). Collectively our results demonstrate how the physical structure of the kelp forests interacts with its surrounding environment to influence the biotic structure of the kelp forest community, and they highlight the importance of environmental drivers of giant kelp in influencing the entire kelp forest community.

Effects of wave disturbance on food web structure -

While the last twenty years have witnessed an explosion in research detailing the general structure of ecosystem food webs in nature {Dunnet et al 2007}, we know much less about how abiotic and biotic forces shape the structure of food webs at the community level. This is a particularly pressing need, as in the next century climate change will influence the frequency and intensity of a variety of press and pulse disturbances in marine ecosystems. Indeed, in California the last fifty years have witnessed an increase in both the frequency and intensity of winter storms {Graham and Diaz 2001; Bormoski et al 2002}. Here at the SBC LTER, we are using our long-term data to address how these disturbances both directly and indirectly alter the structure of kelp forest food webs.

We are using structural equation modeling in conjunction with data form our ongoing long-term monitoring of kelp forest community structure at 11 sites to examine both direct and indirect effects of wave disturbance on the structure of the kelp forest food web. Wave height projections for our sites are obtained from the Coastal Data Information Program (CDIP). Using available literature, institutional archives and conversations with experts we have been able to discern predator-prey relationships between all taxa that we have encountered in our long-term kelp forest monitoring. We are using this information along with the data to determine the network structure of the food web for each site in every year sampled. We have found that these webs differ greatly in topology in both space and time (Figure 16). With these webs, we can calculate different network metrics to describe each individual web (e.g., richness, density of trophic linkages, and ratios of biomass and richness between different trophic groups).

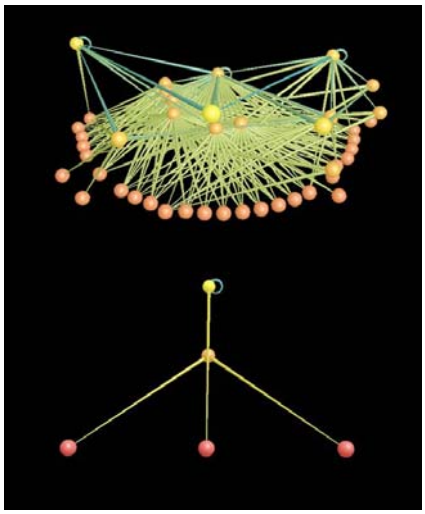


Figure 16: Food webs from Carpinteria Reef in 2008 (top) and Arroyo Hondo in 2005 (bottom). Note that webs differ in both species richness as well as the number and pattern of trophic links.

We have constructed a general structural equation model that independently examines the direct and indirect effects of waves on each of these structural metrics. For each structural metric, our model contains a direct path between average monthly peak wave orbital velocity (i.e., the amount of strong wave disturbance) and the structural variable. It also contains an indirect path; wave disturbance connects to kelp frond density and kelp frond density is then allowed to influence a given structural metric. We have also included a variable representing the cover of sand that works the same way as the wave disturbance variable. Disturbance by sedimentation can have profound impacts on the structure of rocky reefs, and alter the composition of the local biota (Reed et al. 2008). In some models, we are using multiple structural metrics with paths connecting them in a manner consistent with our knowledge of food web theory. For example, linkage density

often positively scales with species richness. Similarly, the number of intraguild interactions increase with the richness of species in higher level trophic groups.

Our results to date show that wave disturbance directly and indirectly increased local species richness and the density of links (# of links / # of species) of food webs (Figure 17). Site-years with high wave disturbance had higher species richness. High wave disturbance also removed large adult kelp, and led to dense thickets of juvenile kelp. Higher kelp density led, in turn, to higher species richness. Higher species richness also led to higher linkage density, which is consistent with theory.

Future models will explore other structural variables to obtain a more detailed understanding of how wave disturbance alters the structure of kelp forest food webs. We also plan to decouple the effect of physical structure of kelp from its role as a food source by using satellite imagery to estimate total kelp biomass available to consumers. Our projections should provide much needed insight into the consequences of altered disturbance regimes caused by climate change.

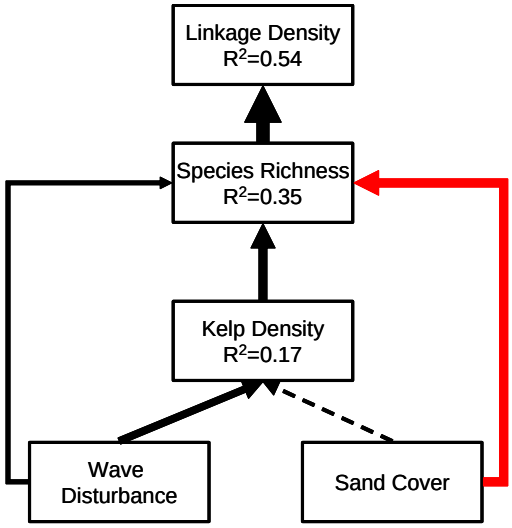


Figure 17: Results from a structural equation model linking different forms of disturbance with kelp density, species richness, and food web linkage density. Path width is proportional to effect size. Red paths are negative. Black paths are positive. Dashed paths are non-significant at p=0.05

<u>Phase shifts and resilience of kelp forest communities in response to pulse and press drivers</u>

Kelp forest landscapes tend to consist of mosaics of patches in distinct community states, and switches between states within each patch are often sudden and dramatic. These patterns are commonly thought of within the framework of phase shifts and alternative stable states, but they also have important implications for understanding how the ecosystem responds to pulse and press drivers. If alternative stable states are present, then the response of the system to a change in one driver will be dependent not only on the condition of the other drivers, but also on the current state of the system. Long-term research in this case is crucial because each community state can persist for many years and because the full behavior of the system cannot be understood without studying how each state responds to changes in different environmental drivers.

The effect of sea urchins on kelp provides a well understood example of the interaction between

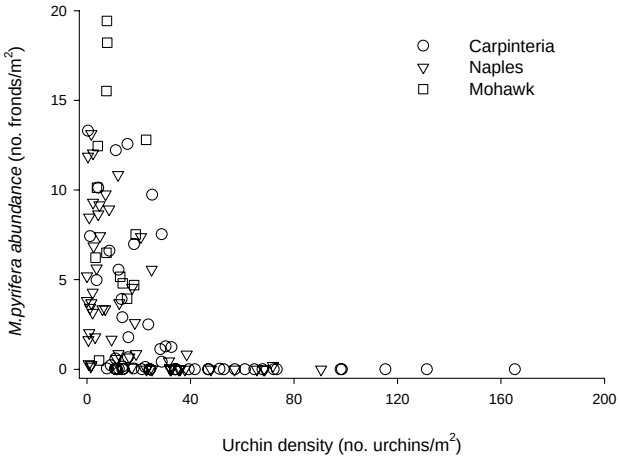


Figure 18. The relationship between kelp frond density and sea urchin density at three reefs in the Santa Barbara Channel. Data represent mean densities observed on a given transect during a given year.

community state and environmental drivers. When present at high densities, sea urchins actively graze and prevent the establishment of kelp and other organisms, whereas at low densities they remain sedentary and feed passively by capturing drifting pieces of algal detritus. Because of this behavioral switch, an environmental driver that promotes kelp recruitment will have little effect on kelp abundance when sea urchin densities are high, but lead to large increases in kelp abundance when sea urchins are rare. We have used LTER monitoring data to show that this feedback is important in Santa Barbara, as giant kelp is only present when urchins are below a certain threshold density (28 urchins m^{-2}), regardless of other conditions (Figure 18). Although the effect of sea urchins on kelp is best known, we have shown that their presence has important effects on other taxa, maintaining low densities of sessile invertebrates and algae and clearing enough bare space that the space competition which typifies these sessile communities is minimized (Arkema et al. *in press*).

We have also been studying another important community shift that appears to exhibit alternative stable states, in which a macroalgal dominated community is replaced by one dominated by the filter feeding sea cucumber *Pachythyone rubra*. Such shifts in community structure have obvious negative effects on primary production, as autotrophs are replaced by heterotrophs, but they also have cascading effects on the entire food chain, with the loss of macroalgae leading to a reduction in micro-crustaceans and in their associated fish predators. We have been studying shifts between these states at a number of sites off Santa Cruz Island in the Santa Barbara Channel and we have documented very rapid shifts and also the persistence of a single state for many years (Figure 19).

We have experimentally explored the interactions between macroalgae and *P. rubra* to determine the mechanisms that explain the shifts between community states and the maintenance of each state (Rassweiler 2008). We found that the sea cucumbers and macroalgae compete strongly for space, which is consistent with results from analogous systems. More surprisingly, we found that the sea cucumbers consume algal spores at a sufficient rate to have a strong effect on algal settlement. This web of interactions, in which one species consumes its competitor (known as intraguild predation) is often associated with alternative stable states. We have used analytical models and spatially explicit simulations to show that in this system intraguild predation reinforces the *P. rubra* aggregations, and may even create alternate stable states (Rassweiler 2008).

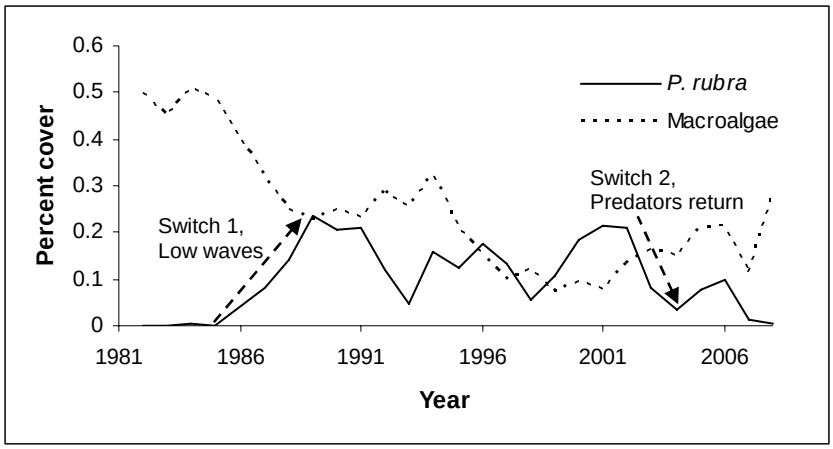


Figure 19. Mean cover of *Pachythyone rubra* and macroalgae at SBC-LTER sites at Santa Cruz Island. Switches in 1986 and 2003 are marked with dotted arrows.

We have also analyzed our time-series of *P. rubra* and macroalgal abundance alongside long term data on potential physical and biological drivers. We found that the switch into the high *P. rubra* phase was most likely triggered by a period of low waves (Figure 19). Because macroalgae rely on waves and water motion to compete for space, their competitive ability was reduced during this period and *P. rubra* was able to establish. Although the low waves were only temporary, representing a pulse disturbance, other mechanisms such as intraguild predation were sufficient to maintain *P.*

rubra dominance once it was established. We found that a different mechanism explained the end of the high *P. rubra* state, with the sea cucumbers' reduction coinciding with the appearance of its major predator, the sunflower sea star *Pycnopodia helianthoides.* This predator represents a press disturbance in the system, and its continued presence explains the continued low density of sea cucumbers. It appears that interactions between the key press and pulse drivers are important in structuring this system, as the initial switch to *P. rubra* dominance was only possible because of the absence of its main predator. A similar pulse disturbance of low waves would be unlikely to allow *P. rubra* to increase if it occurred today given the current levels of predation.

Our work on kelp-urchin state change and our study of shifts between macroalgal and filter feeder dominated communities both mesh well with a broader cross-site LTER interest in phase shifts and alternative stable states. To this end we have been collaborating with scientists from other LTER sites (Jornada, California Current Ecosystem, Moorea Coral Reef, Palmer Station and Harvard Forest) on general processes and mechanisms promoting phase shifts in ecological systems. At an Ecotrends working group in Spring 2009, we initiated two cross-site manuscripts. The first illustrates a new method for detecting of phase shifts in ecological communities, and applies it to datasets from several LTER sites, including two from SBC, one on kelp dynamics and the second on *Pachythyone rubra* populations. That first manuscript is well underway and should be ready for editing at the 2009 ASM. The second manuscript deals with how the detection of phase shifts depends on the spatial scale being sampled and requires observational data on phase shifts that have been collected at multiple spatial scales. We are currently compiling data for this analysis both from within and outside the LTER network.

THEME 3: The indirect effects of pulse and press drivers on kelp forest community structure and function and the feedbacks between structure and function

Direct and indirect effects of disturbance-driven fluctuations in giant kelp abundance on benthic community structure

The giant kelp *Macrocystis pyrifera* is considered both a foundation species (*sensu* Dayton 1975) and an ecosystem engineer (*sensu* Jones et al. 1994) because not only does it provide food and shelter for a diverse array of species, but it also drastically alters the physical environment in which it lives. Hence press and pulse drivers that affect the abundance of giant kelp should have corresponding effects on species that associate with it. Kelp forest communities are characterized by a trophic structure that is unique to shallow reef ecosystems in that the primary space holders (i.e., macroalgae and sessile suspension feeding invertebrates) occupy different trophic levels and thus do not compete for resources other than space. However, competition *within* the two space holder groups for other resources may indirectly affect the strength of competition for space *between* them. For example, shade from the canopy of the giant kelp negatively affects understory algae, which raises the possibility that giant kelp indirectly facilitates sessile invertebrates, via suppression of understory algae. We took a two-fold approach to examine this phenomenon (Arkema et al. 2009). First, we experimentally removed giant kelp from 40 m x 40 m study plots and measured the responses of understory algae and sessile invertebrates. We found a negative effect of giant kelp on both light availability and understory algal abundance and a positive effect on the abundance of sessile invertebrates, which was consistent with an indirect effect mediated by shade from the kelp canopy. Secondly, because frequent disturbance causes kelp populations to fluctuate greatly in space and time, we used observational data on kelp forest community structure from long-term monitoring sites to examine whether the interactions among kelp, understory algae and sessile invertebrates observed experimentally in space led to predictable patterns over time. We found that interannual variability in the abundances of

understory algae and sessile invertebrates were significantly and positively related to interannual variability in the abundance of giant kelp ($r^2 = 0.74$, $P < 0.001$ for understory algae and $r^2 = 0.46$, $P = 0.03$ for sessile invertebrates). Results from structural equation modeling indicated that giant kelp negatively affects understory algae via canopy shading, understory algae negatively affects sessile invertebrates through space competition, and giant kelp indirectly facilitates sessile invertebrates (Figure 20). In fact, the magnitude of the indirect effect of giant kelp frond density on sessile invertebrates (-0.39 x -0.74 = 0.29), was nearly six times greater than the magnitude of the direct effect (= -0.05). The coefficient for the path representing the direct effect of giant kelp frond density on sessile invertebrates was not significantly different from zero, nor were the paths between the percent cover of giant kelp holdfasts and the percent cover of understory algae and sessile invertebrates, suggesting that the significant effects of kelp resulted from shading by kelp fronds rather than competition for space by kelp holdfasts. Our results suggest that the dynamic structure of the kelp forest community is driven in large part by variability in the abundance of a single structure forming species (giant kelp) that has indirect positive, as well as direct negative effects on associated plants and animals.

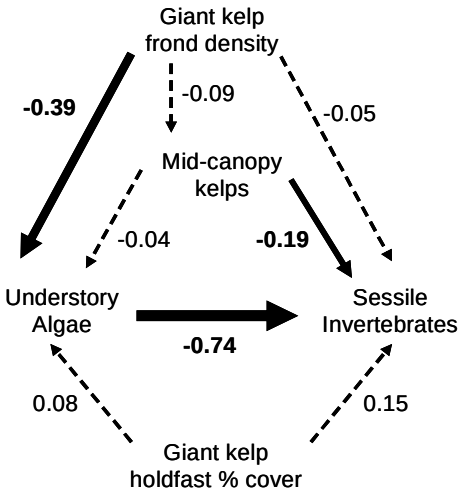


Figure 20. The fitted competition and facilitation model used to estimate the strength of direct and indirect effects. Values are standardized coefficient estimates. Solid lines indicate significant paths ($P < 0.05$). Dashed lines are non-significant.

Disturbance, assemblage structure and the partitioning of primary production among giant kelp, understory macroalgae and phytoplankton

Giant kelp forests are highly productive ecosystems, rivaling those of tropical rain forests. This productivity and its associated standing biomass, however, vary greatly both within and among years in large part due to disturbance from waves (Reed et al. 2008). Such variation in turn affects the entire kelp forest assemblage of primary producers, which are negatively affected by kelp canopy shading (Arkema et al. 2009). To date, estimates of kelp forest production have focused mainly on *Macrocystis*, excluding the diverse community of phytoplankton and understory benthic algae from consideration. Strong competition for light with giant kelp in the forest may cause populations of these two groups of autotrophs to vary out of phase with *Macrocystis*, which may serve to dampen the variability in ecosystem production by kelp forests. To the extent that *Macrocystis* dominates total reef ecosystem NPP, variation in *Macrocystis* canopy will drive corresponding variation in total ecosystem NPP. Alternatively, if NPP of understory algae and/or phytoplankton increases in response to reduced *Macrocystis* canopy, then variability in ecosystem NPP will be reduced. The amount of such compensatory productivity will depend upon the magnitude and temporal lag in the production of understory algae and phytoplankton to the more favorable light conditions associated with kelp loss following disturbance. Phytoplankton are likely able to respond rapidly as the biomass of phytoplankton in the kelp forest is determined by larger scale processes that affect the regional production and transport of phytoplankton (see "Theme 1 Transport of offshore shelf C and N to the inner shelf). In contrast, the recruitment and growth of understory algae is influence by conditions within the forest, and because of

their slower growth rates and seasonal recruitment NPP by understory algae in the kelp forest may lag substantially behind that of phytoplankton following kelp loss.

To examine the role of disturbance in partitioning NPP among different groups kelp forest producers we developed methods for measuring NPP by understory algae *in situ* (Miller et al. 2009) and used these methods to compare rates of NPP by understory macroalgae with those by phytoplankton and giant kelp in an area where giant kelp was removed and in an area was it was left in place. The study was done at Mohawk Reef over a 17-month period in 2007-2008 during which time wave disturbance caused substantial variability *Macrocystis* standing crop and production. We hypothesized that the *Macrocystis* canopy would negatively affect the productivity of understory macroalgae and phytoplankton, and that these effects would vary with *Macrocystis* standing crop. We predicted that understory algae, unlike phytoplankton, would be unable to respond immediately to reductions in *Macrocystis* shading, and one of our goals was to estimate the magnitude of this time lag,. Finally, we compared NPP by *Macrocystis* with that by understory macroalgae and phytoplankton to determine whether natural fluctuations in *Macrocystis* biomass, led to similar fluctuations in the NPP of the entire kelp forest ecosystem.

We found strong evidence that the presence of the giant kelp canopy suppressed production by phytoplankton and understory algae (Miller et al *in review*). As predicted, increased NPP by phytoplankton occurred immediately following disturbance-induced reductions in the kelp canopy, while NPP by understory algae displayed a substantial time lag in response to kelp loss due to the time required to increase its biomass via recruitment and growth. Importantly, we found that in the absence of giant kelp NPP by phytoplankton and an established understory was comparable to that of an established kelp forest community (Figure 21a). Somewhat surprising was our finding that phytoplankton and understory algae contributed on average about one third of ecosystem NPP at the *Macrocystis* canopy control site (Figure 21b).

These results illustrate how indirect effects of pulse and press drivers can influence important aspects of kelp forest structure and function and how the structure of kelp forests as defined by the biomass and species composition of their autotrophs feeds back to influence net primary production, which is a critically important ecosystem function.

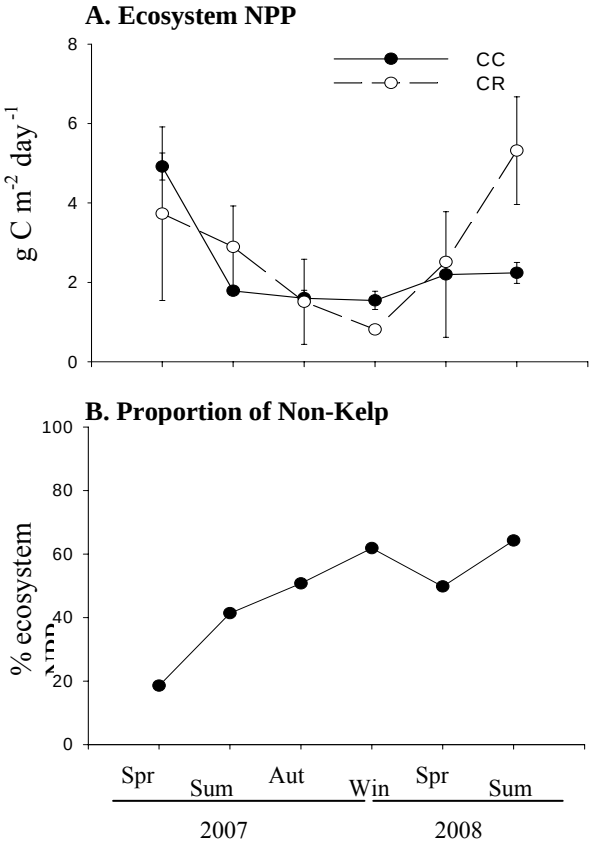


Figure 21. (A) mean ecosystem NPP, including *Macrocystis*, understory, and phytoplankton NPP at the kelp canopy removal (CR) and kelp canopy control (CC) sites at Mohawk Reef. Error bars are 1 standard error. (B). Percentage of non-kelp NPP (Understory + Phytoplankton NPP) inside the kelp forest (canopy control site).

Feedbacks between benthic diversity and grazing intensity in giant kelp forests

In seeking to understand the complex dynamics of communities, researchers have typically concentrated on factors that either regulate community structure or community function. Nowhere has this dichotomy been more evident than in biodiversity research, where separate research traditions have attempted to tease apart either the causes or the consequences of biodiversity. Both are inextricably linked. For example, theories such as the Intermediate Disturbance Hypothesis state the biodiversity is maximized at intermediate levels of disturbance {Connell 1978}. On the other hand, biodiversity ecosystem function research has shown repeatedly that high levels of biodiversity can actually reduce the intensity of disturbance {Hillebrand and Cardinale 2004; Hughes and Stachowicz 2004}. We hypothesize that these two relationships form a feedback between species diversity and disturbance (Figure 22).

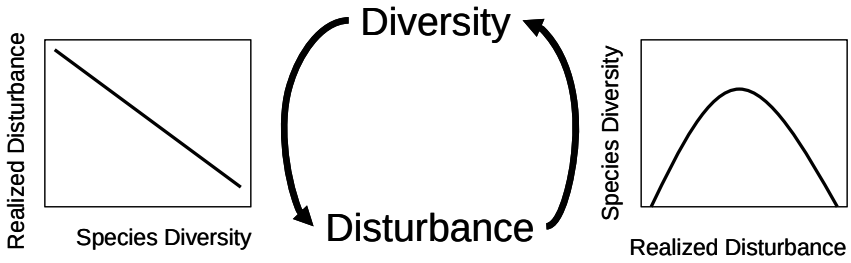


Figure 22: Hypothesized feedbacks between species diversity and disturbance. Diversity of an assemblage determines how much disturbance results from a particular event (e.g., highly diversity communities will potentially experience very little disturbance). The amount of disturbance realized by a community in turn feeds back to alter the diversity of the subsequent assemblage.

Within kelp forests, biological disturbance by sea urchins can drastically alter levels of primary productivity. Sea urchins prefer to feed on kelp detritus, but when starved for drift kelp they change their mode of feeding to one of active grazing. Dense aggregations of grazing sea urchins are common in kelp forests worldwide and their ability to denude the bottom substrate of most sessile species has been well documented. However, yet to be determined is the extent to which the diversity of the benthic assemblage that sea urchins attack influences their effect on the structure of that assemblage and the extent to which the realized amount of disturbance to assemblage in turn feeds back to alter the diversity of the recovered community by altering recruitment, growth, and species interactions.

To investigate the feedbacks between sessile species diversity and sea urchin disturbance, we initiated an experiments in summer 2009 in which we manipulated densities of the purple sea urchin (*Strongylocentrotus purpuratus*) in caged 0.5 m^2 plots that varied in sessile species diversity. Densities of sea urchins were augmented within the caged plots in a response surface design such that plots at all levels of diversity were subjected to a complete range of grazing intensity. The grazing component of this experiment was run for three weeks, after which time we removed the sea urchins and recorded changes in percent cover and species richness of sessile organisms within each plot. We are continuing to monitor the recovery of the benthic community in plots over the following three months. In this manner, we can both examine how initial species diversity alters the impact of grazing, as well as how different levels of realized disturbance (e.g., amount of cover removed) alters future changes in species diversity.

Long-term experiment: Implications of climate change on kelp forest structure and function

Modeling and correlative analyses of our long-term data coupled with cause and effect relationships gleaned from an assortment of short-term mechanistic experiments are providing us with considerable insight into our overarching question of *How do abiotic drivers acting over different spatial and temporal scales interact to influence kelp forest structure and function*? Longer-term manipulative experiments conducted at

ecologically relevant temporal and spatial scales offer a powerful means of verifying predictions generated by our correlative analyses and short-term experiments. Because the giant kelp *Macrocystis* extends throughout the water column it is easily dislodged by large waves associated with winter storms. With this in mind we initiated a long-term experiment in January 2008 to test an assortment of predictions concerning the consequences of consistent annual kelp loss arising from increases in the frequency and intensity of winter storms, which is a trend that has been observed in California over the last 50 years {Graham and Diaz 2001; Bormoski et al 2002}.

To simulate the consequences of increased storm activity we remove all giant kelp once per year in winter from permanent 40 m x 40 m plots at four of our long-term study sites (Arroyo Quemado, Naples Reef, Mohawk, and Carpinteria Reef). Adjacent 40 m x 40 m plots at each site where kelp is left undisturbed serve as controls (Figure 23). These sites vary in wave exposure and level of sea urchin grazing. As such we hope to gain valuable insight over the long-term with respect to how the effects of selectively removing giant kelp vary with different levels of physical and biological disturbance.

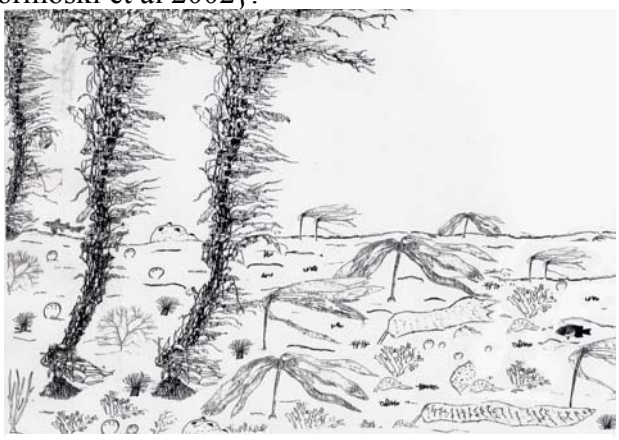


Figure 23. Schematic of the long-term kelp removal experiment showing a giant kelp removal plot with abundant understory kelps and algae on the right and a kelp canopy control plot with giant kelp and a sparse understory on the left.

We are following changes in the biological structure (species abundance and richness of algae, invertebrates and fish), and various ecosystem processes (e.g., NPP by macroalgae, detrital accumulation) 2x per season in fixed transects and quadrats located in each plot. Because there are no off the shelf methods for estimating NPP by understory macroalgae we have been developing a non-destructive approach for examining patterns of understory NPP using species-specific allometric relationships (to estimate biomass) coupled with a bio-optical model. Our bio-optical model incorporates algal biomass, photosynthetic efficiency (derived from laboratory derived photosynthesis vs. irradiance curves for ~20 species that comprise over 95% of the biomass), and photosynthetically active radiation measured once per minute by sensors anchored to the bottom in each kelp control and removal plot.

Our initial results show that giant kelp is among the first species to colonize in spring following its removal in the preceding winter. Dense thickets of young giant kelp have colonized sites with low grazing in each of the first two years. We hypothesize that colonization by giant kelp into the kelp cleared plots will decrease over time as other understory species become established and monopolize light and space. Such changes will undoubtedly influence a diverse assemblage of kelp forest consumers that depend directly and indirectly on giant kelp for food and/or shelter.

In addition to examining potential consequence of climate change, the long-term removal of giant kelp will also provide a wealth of information on how the kelp forest system responds in the absence of its foundation species. Moreover, the design of our experiment (in terms of plot size and replication among sites) allows it to serve as a template for both short and long-term investigations that explore a wide variety of ecological issues and questions pertaining to the presence (or absence) of giant kelp. Indeed our current studies of kelp forest food webs and feedbacks between ecosystem structure and function were designed to make use of the long term experiment

Information Management

SBC's information system manages two major resources, datasets and a bibliography of citations, both of which are displayed in local catalogs and shared as needed. Several metadata components are necessary to describe a data resource, e.g., people, places and projects (e.g, experiments). These components can also provide the basis for website subject areas, and an central metadata system will enable links between the two. SBC's metadata system is based on EML, and we have developed other compatible XML schemas to meet local needs when necessary. For data exchange and archive, ASCII tables have proven to be the most flexible and efficient for highly varied data. Because these tables can become cumbersome over time, we have developed a generic tool for loading data into a relational database so that it can be queried with web forms generated from its EML metadata.

Publications database

Like our datasets, SBC publications are described by the EML schema and are available online http://sbc.lternet.edu/publications. We have continued to extend EML for the reporting and multi-use needs of bibliographic references. We are also continuing work on the web application to accommodate searches and reports, and to increase speed.

Query interface for EML datasets

SBC's growing data time series requires tools for querying and sub-setting data tables. We have developed a generic web application which can be applied to many types of data tables described by EML (availablethrough links at http://sbc.lternet.edu/data). This tool reads EML metadata, inserts the data table into a relational database and creates a map interface and form so that a user may subset large data products. The application takes advantage of established community standards and accommodates a variety of data tables. The application's use of the EML format means it can potentially be applied by many other research groups.

SBC-LTER Website

The SBC website (http://sbc.lternet.edu) has been converted from a collection of static pages to a scripted system which streamlines the addition of new material and facilitates editing of dynamic menus or style changes. During the conversion, new material was added so that the website is compliant with LTER web site recommendations.