Biodiversity and Upwelling Dynamics of the Galápagos Marine Reserve

NNG04GL98G Final Technical Report:

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This is the final technical report for National Aeronautics and Space Administration (NASA) Biodiversity and Ecological Forecasting grant NNG04GL98G: "Connectivity and Upwelling Dynamics in the Galápagos Marine Reserve (GMR)", Counterpart US-AID

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Fig 1. Participants in NASA NNG04GL98G: "Connectivity and Upwelling Dynamics in the Galápagos Marine Reserve".

No. 518-A-00-03-00152-00 to the Charles Darwin Research Station (CDRS) and UK Darwin Initiative Project No. 14-048. Participants from 6/15/04 – 6/14/08 are shown in Fig. 1. The effort focused on natural and human-induced variability in the ocean response to that variability and how these changes affect the biodiversity of GMR. This effort was the first systematic study of the oceanographic setting controlling marine biodiversity. We focused on characterizing oceanographic processes that have a strong signature associated with climate change and realized and potential effects on GMR by carrying out an integrated program of remote sensing, physical, chemical & biological oceanography (UNCW/NCSU) and biodiversity and ecosystem processes (CDRS). The focus was on how filaments of Equatorial Undercurrent (EUC) propagate across the GMR, varying in position and strength and their differential impact on nutrient supply and larval transport. In addition, the Galápagos provide an ideal "field laboratory" for assessing how global warming impacts marine ecosystems, as well as, effects of events of extreme climate variability associated with ENSO. On shorter time-scales, the Galápagos acts as a natural experiment for measuring effects of annual to interannual variability on flora and fauna. During the initial study, we did experience a weak/abortive El Niño in 2006 and effects of an extended La Niña in 2007.

Field Program

• *Oceanographic Cruises:* We took advantage of the already funded US-AID (Banks, et al., 2006) ecosystem-monitoring program to support field operations. The joint NASA/US-AID program carried out 10-day surveys (Fig 2) of the GMR on the *M/V SIERRA NEGRA* of the Galápagos National Park Service (GNPS). 5 hydrographic surveys were conducted during 2005/07: Mar 17-28, 2005 (Mar05), Nov 22-Dec 3, 2005 (Nov05), Jun 26-Jul 4, 2006 (Jun06), Nov 14-23, 2006 (Nov06) and May 17-27, 2007 (May07). About 59 stations per cruise were occupied to 80–100 m using a SeaBird Seacat CTD and Seapoint Fluorometer. Surface samples were filtered for plankton-related chemical and optical analyses. These stations provide a spatial context for the temporal record of oceanographic conditions obtained at mooring and monitoring sites. Net tows for zooplankton to 20m and for near surface phytoplankton and surface water samples collections for microscope-based phytoplankton and microzooplankton class & species determinations were made at each station and preserved synchronously with collections for chlorophyll, total suspended matter and chromophoric dissolved organic matter. Satlantic HyperSAS underway and HyperPro profiling systems configured with 166-channel MiniSpec radiance and irradiance sensors were used to measure hyperspectral data during daylight to collect underway along track surface and station profiles of remotely sensed data.

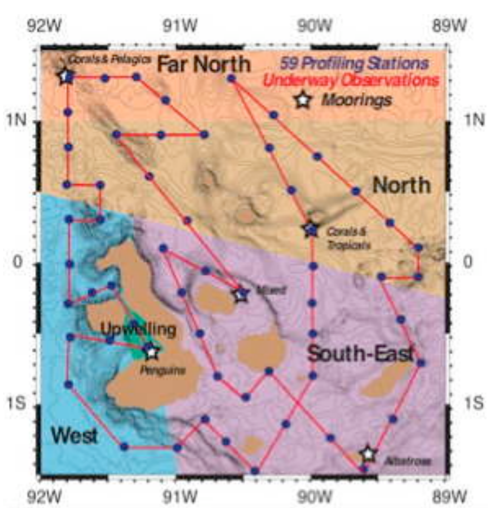

Fig.1 Standard cruise track.

• *Moored Data.* YSI Sondes with Conductivity, Temperature, Pressure, Oxygen, and Fluorescence were deployed at 5-m depth within the 5 biogeographical regions identified through analysis of inshore subtital community composition (Egar et al., 2006). 5 moorings were deployed in March 2005 and recovered in May 2007 ("stars" - Fig. 2) using divers. The moorings were turned around at 6–8 month intervals, because of limited logistic support, leading to ~50% data recovery. All data have been processed.

• *Ecological Surveys*. CDRS divers conducted ~900 nearshore ecological surveys at Isabela, Fernandina, Wolf, Darwin, Genovesa, Santiago, Santa Cruz, San Cristobal, and Española Islands with biannual/seasonal repetitions across 60-70 sites in addition to and during the 5 cruises. Subtidal dive surveys at 6 & 15 m depth, evaluated changes in rocky reef communities under different management regimes within natural variability between biogeographic regions for sessile macroinvertebrates, demersal reef fish, mobile macroinvertebrates, and mesogastropods. Vertical habitat mapping surveys were run to 30m at ~220 sites. Other CDF activities included zooxanthellate coral mapping and monitoring of last remaining reef communities, species distribution mapping and predictions, local fisheries and marine tourism analysis, and discovery of equatorial kelp beds (Graham et al, 2007).

• *Plankton Analysis:* A 20 um phytoplankton net was towed at the surface to collect representative samples. Plankton samples were preserved in 4-6 % buffered formalin and split in half using a Folsom Plankton Splitter for separate identification and enumeration by the CDRS and NCSU. Phytoplankton species were identified using taxonomic keys and abundance are expressed as individuals m^{-3} using a FlowCAM where forward scattering or auto-fluorescent properties of photosynthetic plankton can be exploited by flow cytometry to characterize abundance, size distribution and community structure. In summary, phytoplankton group characterization includes FlowCAM, HPLC pigment determinations with ChemTax, and absorption spectra. Total suspended matter and CDOM were also characterized. Zooplankton net (335 μm) tows to 20 m were made at each station, samples were preserved and split for NCSU/CDRF. Samples are being counted/identified using standard taxonomic techniques.

Data Analysis

• ***Water Mass Variability***. Data from Mar05, Nov05, and Jun06 are discussed in *Sweet, et al. (2007)* and provide snapshots of the surface water (<80 m) properties over the archipelago during hot and calm extremes of the wet season (~Dec-Apr), cooler and windier conditions of the Garúa (~May-Nov), and conditions transitioning between the two. The surveys captured the surface properties near the extremes and midpoint of the annual cycle of mean sea surface temperature (SST) and winds. Cooler SST occurs in boreal summer and fall as southeast trades strengthen which coincides with the EUC becoming weaker and deeper below a strengthening westward South Equatorial Current (SEC). Opposite conditions are generally found in boreal spring. Tropical Surface Waters (TSW) (Salinity <34) fill the GMR from late boreal fall through early boreal spring from the North Equatorial Contercurrent (NECC). In late boreal spring through early boreal summer the EUC strengthens, resulting in Equatorial Surface Waters (ESW) throughout the GMR. *ESW are continuously present west of Isabela, where the EUC upwells as it interacts with the islands, and often advected from the east into the GMR in the "cold tongue" by the SEC. Upwelling west of Isabela creates a consistently shallow 20°C thermocline, which remains elevated across the GMR.*

• ***ENSO Effects****:* Data from Nov06 and May07 cruises moored observations in the GMR and NOAA TAO (Tropical Atmosphere Ocean Array) and wind and SST data obtained from the NASA Physical Oceanography Distribution Active Archive Center's were used to study ENSO related water mass variability in the Archipelago *(Sweet et al. 2008). The annual cycle reveals minimum meridional winds and maximum SST in boreal winter/spring and opposite conditions in boreal summer/fall (Fig. 3a.).* The Nov06 survey occurred during transition from Garúa (misty season; May-Nov) to wet (Dec-Apr) season, while the May07 survey occurred during wet-to-Garúa transition. Phase and magnitude of respective minimum and maximums in SST and winds are modulated by ENSO-phase changes. Anomalies of SST within the GMR and the Niño 3.4 region (Fig. 3b) reflect the trends established for the annual cycle within the eastern equatorial Pacific (Yu and McPhaden 1998; Johnson *et al.* 2002) and the archipelago *(Sweet et al., 2007).* Yet, *upper ocean properties during Nov06 and May07 surveys reveal strong modification by effects associated with ENSO-phase changes. Effects within the GMR occur mainly within the thermal structure, with >10-m changes in thermocline depth and >2°C changes of SST. Sea Surface Salinity remains relatively unchanged with small ~0.2 changes that result in little to no influence on water mass types. These findings are similar to those of Fiedler and Talley (2006).* Moored temperature data indicate that the GMR is sensitive to and affected by Kelvin waves, which generate intense and prolonged temperature anomalies (Sweet et al. 2008). Observations at the TAO array show that temperature anomalies progressively increase eastward. Thus downwelling and/or upwelling from equatorial waves result in a more intense signal in the GMR, since the thermocline is shallower in the east, thereby creating a stronger thermal stratification in the upper water column. Our mooring records extend the measurements of the TAO array into the GMR, and show temperature changes similar to and occasionally greater than those at 95°W. A weak El Niño was observed during 2006 with 4 Kelvin waves transiting the Archipelago in ~Feb, May, Oct 2006, and Jan 2007, while the May 2007 survey occurs during an anomalously cool period. Soon after passage of the last downwelling Kelvin wave in Dec 2006, SST clearly shows a cold-water anomaly in the GMR. The event, although, is not classified a La Niña until Aug 2007. Any change in upwelling intensity and distribution is of importance to GMR managers as the process supplies nutrients to phytoplankton, which feed the biodiversity. Results show ENSO-related variability produces a >15% mean change in observed Chl *a*. These results are in line with trends observed in averaged SeaWiFS data (2°N-2°S, 92°-88°W).

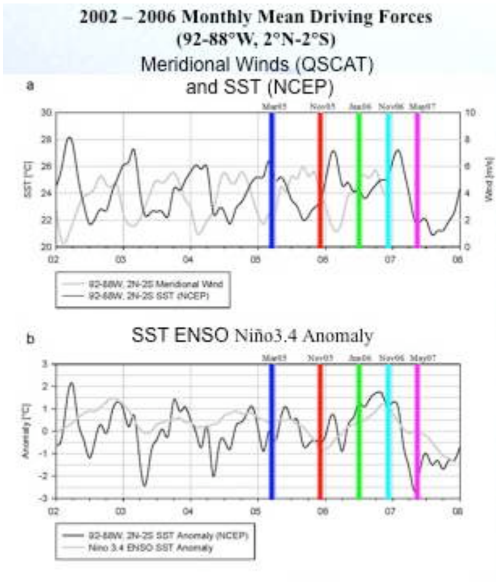

Fig. 3. Driving forces for 2002 –

• ***Tropical Instability Waves (TIW):*** Our moored data also displays the effects of TIW on properties of the GMT (Sweet, 2008). TIW cause significant and widespread upwelling across the GMR. Moored instruments capture oscillations of TIW, with the passage of 3 waves between Aug 28 and Oct 13, 2005 (Fig. 4). TIW upwelling stimulated a >25% increase in Chl *a* over the GMR. Meanwhile, the10-yr and TIW-period mean Chl *a* increases along the equator from 110°W towards the GMR. This trend is attributed to an eastward rise of the thermocline/EUC supplying nutrients (iron) to the cold tongue, generating high Chl *a* levels. The disproportionate Chl *a* response of the GMR compared to 95°W during the TIW highlights importance of upwelling (iron-additions) within the GMR. *TIW may be fundamental to the ecology of the Galapagos, with rhythmic pumping and pulses of Chl that wash across the GMR.*

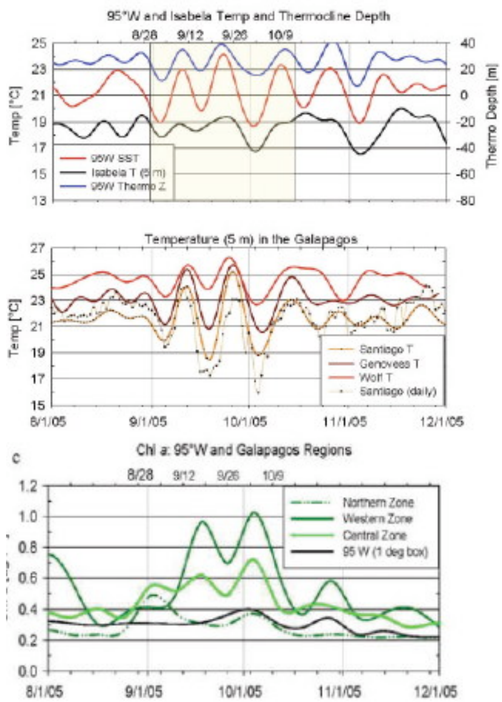

Fig.4. Tropical instability waves in temperature and chlorophyll records.

• *Phytoplankton Biomass Distribution.* Phytoplankton are the base of the ecosystem food chain for many higher trophic organisms, so identifying phytoplankton biomass distribution is the first step in understanding the dynamic environment of the GMR for effective management. This was the first project to combine remote sensing (Moderate Resolution Imaging Spectroradiometer (MODIS) and hyperspectral surface acquisition system derived chlorophyll) and in-situ techniques (chlorophyll fluorescence, nitrate, salinity, and temperature) to capture progression from normal conditions in Mar 2005 and Jun/Jul 2006, conditions similar to a La Niña event in Nov/Dec 2005, to a mild El Niño in 2006 *(Schaeffer et al., 2008).* Islands in the eastern GMR, such as San Cristobal and Española, were first to experience El Niño and the southern migration of the Equatorial Front and suppressed EUC upwelling. Pinta, Marchena, Genovesa, San Cristobal, Espanola Islands, and eastern sides of Santiago, Santa Cruz, and Floreana Islands experienced greatest decrease in phytoplankton biomass during the 2006 El Niño. The easternmost islands of the GMR also experience the greatest change during La Niña. During conditions similar to a La Niña in 2005, San Cristobal and Espanola experienced greatest increase in phytoplankton biomass. This was also the first project to specify persistent regions in the GMR with high phytoplankton biomass (>0.4 mg m^{-3}), supported by EUC upwelling, that are small enough to actively manage as possible resource "hotspots" *(Schaeffer et al., 2008)*. Combination of remote sensing imagery and in-situ data allowed identification of 6 productive habitats (surface salinities 34, temperatures 24°C, and Chl a >0.4 mg m^{-3}) located west of Isabela, southwest of Floreana, south of Santa Cruz, between Santiago and Santa Cruz, and in the eastern side near San Cristobal. *Model results coupled with hyperspectrally derived chlorophyll indicate productive habitats may occur for short periods and at distances from islands when the EUC and SEC collide* *with the seamounts north of Isabela Island. All 6 productive habitats were related to topographic upwelling from the EUC into surface waters.*

• ***Remote Sensing of Phytoplankton Groups:*** Ocean color monitoring has primary focused on Chl *a*. However, Chl *a* is not sufficient for understanding the global carbon cycle or global oceanic ecosystem distributions. Specific phytoplankton groups and/or species need to be identified. Hyperspectral measurements provide one approach for identification; however, satellite remote sensing presently is limited to multi-band sensors. *We are currently addressing this issue with a multidisciplinary approach to integrate space-based remote sensing data with in situ biological, physical and chemical data from the GMR to identify phytoplankton groups.* Phytoplankton groups associated with their community optical signatures will be identified by ship-based sample collection and hyperspectral sensing, along with laboratory measurements and analyses, including microscope identification, pigment analyses, and spectral absorption. Specific water-leaving radiance, calculated from optical signatures, and spatial distribution of phytoplankton will be linked to satellite remote sensing**.** *Preliminary results appear promising.*

• ***Ecological Surveys.*** Over 850 subtidal species (fish, sessile and mobile meso-macrofauna and marine algae) were followed seasonally across 64 subtidal rocky reef sites during 2004/07 (Fig.5) showing strong differentiation and fragmentation in community composition between distinct temperate, tropical water mass and upwelling habitats. Most threatened (IUCN criteria) and endemic species were associated with cold upwelled habitat identified from cruise and satellite hyperspectral records *(Schaeffer et al, 2008).* Community shifts were observed at seasonal time scales and species-specific effects (such as annual warming and cold shock coral bleaching) linked to passage of internal waves restructuring the thermocline, altering the productive environment and vertical community structure. Bases on CDF surveys, red-listing processes in 2007 identified over 43 Galapagos marine species as *globally threatened.* Community relative abundance and size structures together with EcoPath trophic modeling shows a worrying prevalence of urchin overgrazing presumably preventing resettlement of habitat forming species yet promising new evidence for importance of no-take coastal zones in conserving biodiversity and marine resources that harbor the last refuge for important fished species of reproductive age.

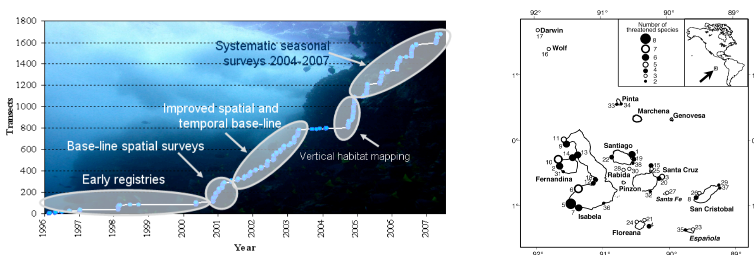

Fig 5. Subtidal sampling effort 1994-2007 and known distributions of threatened marine species (right; after Edgar et al, in revision).

Modeling

Efforts to date have been divided between simulating the ocean circulation and water masses using the University of Miami's Hybrid Coordinate Ocean Model (HYCOM) (Liu et al., 2008a) and development of ecological models. The most advanced is a trophic model of a Galápagos subtidal rocky reef for evaluating fisheries/conservation strategies (see Okey et al., 2004, 2008).

• ***Hydrodynamic Model****:* Ocean circulation and water masses around the Galápagos Archipelago are being studied using UMiami's Hybrid Coordinate Ocean Model (HYCOM) *(Liu et al., 2008).* A four-level nested-domain system with resolutions from 0.04° x 0.02° in the Galapagos region (tested to 0.02° x 0.01° but simulations around the GMR shows a 0.04° x 0.02° resolution is suitable to study observed variability), to 0.12° x 0.06° in Eastern Tropical Pacific (ETP), to 0.48° x 0.24° for Pacific Ocean, to 1.44°x 0.72° for global ocean has been implemented. Daily surface fields obtained from NCEP and wind forcing from QuikSCAT is used to drive the simulations. *Model results (Sweet et al., 2007; Liu et al., 2008)* are quite similar to that described using field data. *The model shows a seasonal cycle in speed and transport of the EUC, reaching a maximum during late boreal spring/early summer and minimum in late fall which agrees with observations of the EUC by TAO array*. This seasonal cycle is disrupted during El Niño when the westerlies collapse resulting in weakened to total lack of the EUC. The far northern region of the GMR is characterized with warmer, fresher water and the deepest mixed layer depth as a result of Panama Current waters from the northeast. *Water masses over the remainder of the region result from a mixing of cool Peru Current and upwelled Cold Tongue waters entering from the east to the southeast mixing with upwelled EUC waters.*

HYCOM was also use to conduct various climate simulations, in particular the El Niño cycle *(Liu, et al., 2008b).* ENSO events are simulated using daily atmospheric forcing derived from the NCEP/NCAR reanalysis data for 1949-2006. *The results indicate that with prescribed atmospheric forcing, HYCOM model can accurately simulate the major characteristics of ENSO events Liu, et al. (2008b). The correlation coefficient between the simulated SST anomalies (SSTA) and observed SSTA in the Niño3.4 region is 0.73.* However, the simulated SSTA have an anomalous rising trend for which we are performing diagnostic studies to understand.

• ***Biogeochemical Modeling****.* The biological response to physical forcing within the GMR, is also being simulated by a ***nutrient – phytoplankton – zooplankton – detritus model*** (NPZD, Oschlies 2001) coupled to the inner nest of the hydrodynamic model *(Liu et al., 2008c).* These efforts have just begun as we now have a physical model with sufficient resolution to meet the needs of the biological simulations. Wiggert et al. (2005) conclude that the greatest challenge in ecological modeling appears to involve reproducing observed levels of physical variability (e.g., upwelling and rapid mixing events, filaments and mesoscale eddies). They conclude that high frequency physical processes are directly responsible for major biogeochemical events that are, in turn, responsible for a large fraction of annual production and export flux. Until physical variability is resolved and their biogeochemical effects accounted for, understanding of biogeochemical variability will not be impacted by increasing ecosystem model complexity.

• ***Tropic Ecosystem Modeling.*** A balanced tropic model of a Galapagos rocky reef system was constructed using ***Ecopath and Ecosim*** *(Okey et al., 2004).* ***Ecopath with Ecosim (EwE)*** enabled exploration of hypotheses about system dynamics and potential solutions to conservation concerns about overfishing. In the Galapagos Rocky Reef Systems, simulations showed that current catch rates of *pepinos* (sea cucumbers) are unsustainable. Application of different management strategies show that exclusion of fishing from 23% of total reef area, ie., an hypothetical non-extractive zone, prevented extinction of *pepinos* given 1999 - 2000 catch rates. But even with 23% of the area protected, *pepinos* were predicted to decline overall to a stable 36% of current biomass. *Pepinos* biomass was predicted to increase to 8 times that of current levels if *pepino* fishing were stopped. EwE results constitute a first step to explore/understand the nature and dynamics of the Galápagos marine ecosystems. We continue to evaluate/refine the rocky reef ecosystem model in parallel with ongoing baseline monitoring program and improving model forcing using our NPZD Model and remotely sensed productivity data. *This approach will help evaluate potential effects of human activities and management policies such as zone-based fisheries and conservation management.*

Summary:

We have made great strides in our answering our original hypotheses: 1. Filaments from the Equatorial Undercurrent that propagate across the Galapagos platform which vary in position and strength, on where they end up, and their impact on nutrient supply and potential larval transport through the system are quite probably the most important defining physical process to influence the very high local production at certain sites; 2. Combination of remote sensing imagery and in-situ data allows identification of 6 productive habitats (surface waters with salinities 34, temperatures 24°C, and Chl a >0.4 mg m^{-3}) located west of Isabela Island, southwest of Floreana Island, south of Santa Cruz, between Santiago and Santa Cruz Islands, and in the eastern side near San Cristobal Island. 3. Galápagos provide an ideal “field laboratory” for assessing how climate change will impact marine ecosystems, as well as, the effects of events of extreme climate variability associated with ENSO; 4. On shorter time-scales, the Galápagos acts as a natural experiment for measuring the effects of annual to interannual variability on flora and fauna; 5. Species and communities retreat to natural warm- or cold-water refuges on particular islands, and expand back within their former range during the years between El Niño and La Niña; 6. Model results coupled with hyperspectrally derived chlorophyll indicate productive habitats may occur for short periods and at distances from islands when the EUC and SEC collide with the seamounts north of Isabela Island; and 7. TIWs may be fundamental to the ecology of the Galapagos, with its rhythmic pumping and pulses of high Chl that wash across the GMR.

PhD Students:

William Sweet (2008) Mechanisms of Variability within the Upper Ocean of the Galápagos Archipelago.

Anita McCulloch (Spring 2009) Phytoplankton and Community Zooplankton Structure of the Galápagos Marine Reserve

Yanyun Liu (Spring 2009) Simulation of Ocean Circulation around the Galápagos Archipelago using a HYbrid Coordinate Ocean Model (HYCOM)

Publications: (* Students)

Banks S.A. (2003) SeaWiFS satellite monitoring of oil spill impact on primary production in the Galápagos Marine Reserve. Marine Pollution Bulletin. Vol. 47(7-8), pp. 325-330

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Liu, Y., L. Xie, and J. Morrison, Simulation of El Niño-Southern Oscillation (ENSO) using a HYbrid Coordinate Ocean Model (HYCOM). 28 Conference on Hurricanes and Tropical Meteorology, American Meteorological Society, April 26-May 2, 2008, Orlando, Florida.

Xie, L., Yanyun Liu, And John Morrison, Simulating Ocean Circulation From Global Ocean To Marginal Seas Using The Hybrid Coordinate Ocean Model: The Galapagos Example. 2007 International Workshop on Marine Physical Variations in marginal seas and their environmental impact. October 29-30, 2007, Qingdao, China.

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Schaeffer, B. A., J. Morrison, D. Kamykowski, G. C. Feldman, L. Xie, Y. Liu*, W. Sweet*, A. McCulloch*, and S. Banks (2008) Phytoplankton biomass distribution and identification of productive habitats within the Galapagos Marine Reserve with remote sensing, a surface acquisition system, and in-situ measurements. Rem. Sen. Enviro. 112 (6): 3044-3054.

Sweet*, W. V., J. M. Morrison, D. Kamykowski, B. A. Schaeffer, S. Banks and A. McCulloch*. 2007. Water mass seasonal variability in the Galápagos Archipelago. Deep-Sea Res. Part I. 54(12): 2023-2035.

Liu, Yanyun*, Lian Xie, John M. Morrison and Reiner Bleck. 2008. Simulation of the Ocean Circulation around the Galápagos Archipelago using a Hybrid Coordinate Ocean Model (HYCOM). Journal of Geophysical Research. **(In Review)**

Sweet*, W. V., J. M. Morrison, D. Kamykowski, B. Schaeffer, S. Banks. Observations of the 17-day Tropical Instability Wave and its affects on the Galapagos. Deep-Sea Res. **(In Review)**

Liu, Yanyun*, Lian Xie, John M. Morrison, and Reiner Bleck, Simulation of ENSO Events in the Eastern Tropical Pacific using a Hybrid Coordinate Ocean Model (HYCOM). Journal of Geophysical Research. **(In prep)**

Liu, Yanyun*, Lian Xie, John M. Morrison, Reiner Bleck. A coupled Hybrid Coordinate Ocean Model (HYCOM) circulation and NPZD Biogeochemical Model of the Galápagos Marine Reserve. Journal of Geophysical Research. **(In prep)**

McCulloch*, Anita, Daniel Kamykowski, John M. Morrison. ENSO-related variability in phytoplankton community structure of the Galápagos Marine Reserve. **(In prep).**

McCulloch*, Anita, Daniel Kamykowski, John M. Morrison. Spatial and temporal variability of phytoplankton community structure of the GMR based on pigment analysis. **(In prep)**

McCulloch*, Anita, Daniel Kamykowski, John M. Morrison. Inter-seasonal variability of plankton community structure of the Galápagos Marine Reserve.**(In prep)**

Schaeffer, B., G. Kirkpatrick, T. Miles*, D. Kamykowski, and J. Morrison. Identification and distribution of phytoplankton classes in GMR with optical phytoplankton discriminator and high performance liquid chromatography. Applied Optics **(In Prep)**

POSTERS Presented at Biodiversity and Ecological Forecasting Team Meetings:

2006:

A.M.Hopkins, B.A. Schaeffer, D. Kamykowski, & J.M. Morrison, Using Optical Techniques to Identify Case Waters in the Galápagos Marine Reserve

A.M. McCulloch, W.V. Sweet, B.A. Schaeffer, J.M. Morrison, D. Kamykowski, and S. Banks. Seasonality of phytoplankton distributions in the Galapagos Marine Reserve

B. A. Schaeffer, W. V. Sweet, J. M. Morrison, D. Kamykowski, S. Banks, A. McCulloch and G. Sinclair , Changing seasons for the Galapagos Marine Reserve.

T.N. Miles, B.A. Schaeffer, G.J. Kirkpatrick, D. Kamykowski, & J.M. Morrison. Relative Phytoplankton Concentrations During Normal and Mild El Niño Conditions in the Galapagos Archipelago Determined through In-Situ Absorbance in an Optical Phytoplankton Discriminator.

2008:

Blake A. Schaeffer, D. Kamykowski, J. M. Morrison, S. Banks, A. McCulloch, and W. V. Sweet. Putting the puzzle together: Connecting the HyperSAS with BreveBuster absorbance spectra, fluorometer, extracted chlorophyll and MODIS data.

Yanyun Liu, Lian Xie, J. M. Morrison, D. Kamykowski, W. V. Sweet. Simulation of Ocean Circulation around Galápagos Archipelago using a Hybrid Coordinate Ocean Model (HYCOM)

W.V. Sweet', J.M. Morrison, D. Kamykowski, B.A. Schaeffer, S. Banks, A. McCulloch. Water Mass Seasonal Variability in the Galápagos Archipelago

W. V. Sweet, J. M. Morrison, D. Kamykowski. Tropical Instability Wave Interactions within the Galapagos Archipelago

Data:

The final data collected from this project are being assembled in final form on a DVD to be submitted to the NASA Biodiversity and Ecological Forecasting Program and national archives. This will happen by 1/1/2009 --- it has been delayed because of the quantity of data collected and application of final calibration and quality control, much of which is currently being carried out as the final publications are being prepared for review.