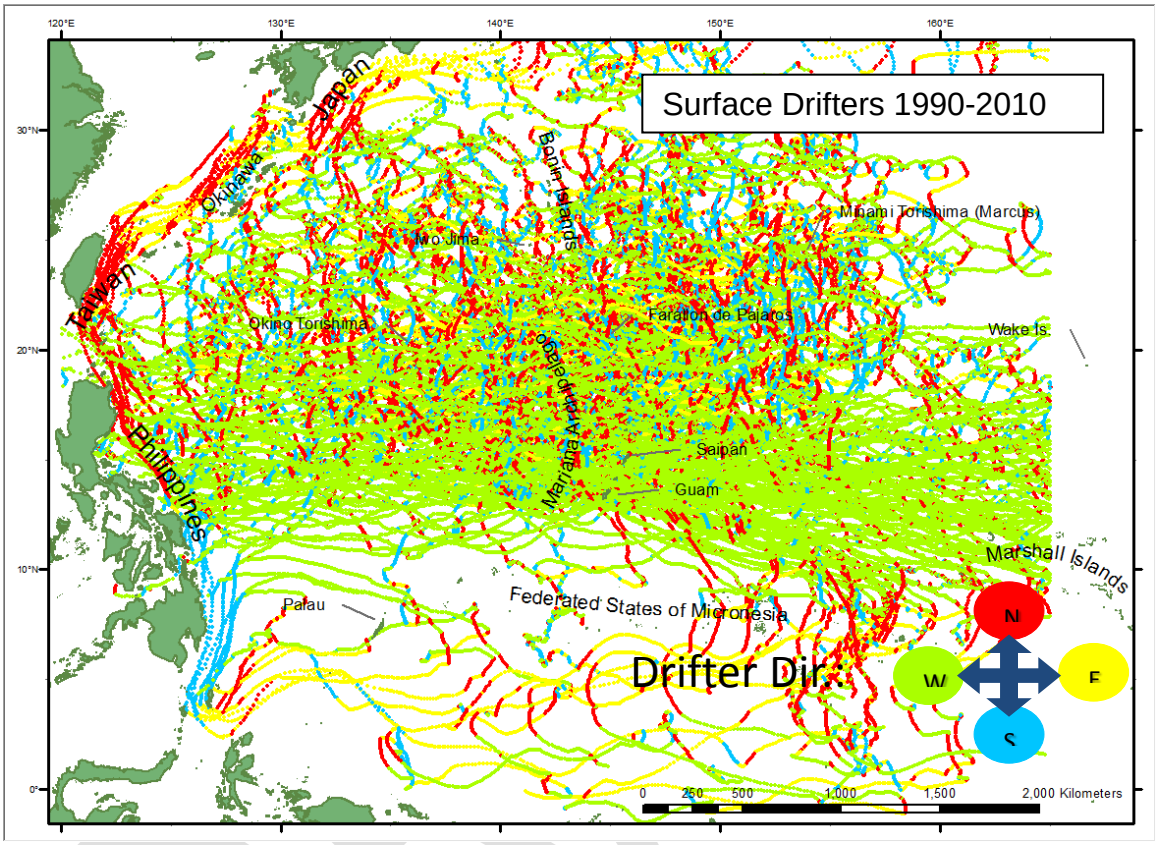
Mapping pathways of larval connectivity in the Mariana Islands



A cooperative investigation between NOAA's National Centers for Coastal Ocean Science, Coral Reef Conservation Program, National Marine Fisheries Service, the Commonwealth of the Northern Mariana Island's Division of Environmental Quality, Division of Fish and Wildlife, Coastal Resources Management, and Guam's Coastal Management Program, Division of Aquatic and Wildlife Resources, and the University of Guam Marine Lab

The CORAL REEF INITIATIVE of the Commonwealth of the Northern Marianas

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About this document

This work plan was created to inform project partners and other interested groups about the ocean-current mapping and larval connectivity study underway for the Mariana Archipelago. The document provides a list of project objectives and a road-map for completing them. It is based on discussion with project partners in CNMI and Guam and may be modified based on preliminary results to best meet partner needs. For more information contact matt.kendall@noaa.gov

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In collaboration with…

Introduction

The proposed collaborative project will map ocean currents and identify important sources and destinations for pelagic larvae of reef organisms in the Mariana Archipelago. The Commonwealth of the Northern Mariana Islands (CNMI) comprises the northern part of the chain and is made up of 14 islands extending over 600 kilometers. Guam is the largest and southernmost island in the chain. The islands lie along the northern edge of the North Equatorial Current in the western Pacific Ocean. Many of the marine organisms that inhabit the coral reef ecosystems of the region including many reef fish, broadcast spawning corals, giant clams, crown-of-thorns starfish and a diversity of other fauna possess a pelagic larval phase. This phase is capable of distributing the larvae 10s to 1000s of kilometers away. The connectivity among island populations that results from this transport is important because it means that the ecology, conservation, and management of each place in the Mariana Archipelago is somewhat dependent on decisions made at other locations. It has become clear that a wide range of management decisions such as planning a regional network of MPAs that are resilient to disturbance, managing sustainable fisheries, and mitigating natural or anthropogenic impacts are dependent upon an understanding of larval transport. Sufficient larval sources must be protected and spaced appropriately such that islands can successfully repopulate between disturbance events or fishery harvest.

The proposed study will provide a characterization of ocean currents in and around the archipelago and discuss their potential influence on important sources of larvae for maintaining reef ecosystems in the Marianas. The project will complement current conservation, research, and management activities in the region including the Micronesia Challenge, US and Marianas Coral Reef Initiatives, and the Marine Protected Area Programs at CNMI and Guam, and biogeographic studies at the University of Guam. The project will be similar in scope and approach to the recently completed "Biogeographic Characterization of the Samoan Archipelago: Chapter 3 Currents and Larval Connectivity" (Kendall and Poti, Eds 2012: summary and pdf available at http://ccma.nos.noaa.gov/ecosystems/coralreef/samoan_archipelago/).

This study will address a variety of factors that can affect the transport of larvae among islands. Most obviously it is necessary to understand the speed, direction, and seasonality of the ocean currents by which larvae are transported. It is also necessary to understand how aspects of the larvae themselves can affect their transport. Size of source populations, timing of spawning, duration of the larval period, daily mortality rates, sensory and swimming capabilities, and even random chance arising from the turbulent nature of ocean flows can all affect the probability that larvae will be transported from a source island to a particular destination.

The overall goals of this proposed study are to:
1. Quantify and describe regional ocean currents in the Mariana Archipelago,
2. Model the transport pathways of virtual larvae among island sources in the region,
3. Identify key sources and destinations of larvae for each island or island group,
4. Quantify the influence of various combinations of larval life history characteristics (e.g. larval longevity, daily mortality rate) on those connections and,
5. Transfer the capability to conduct additional connectivity analyses to interested partners (PENDING TRAVEL FUNDING)

To achieve these goals, we will combine observational data on ocean currents from satellite – tracked surface drifters with simulations of larval dispersal in a regional hydrodynamic model. An important counterpart to this study, genetic analyses of tissue samples among islands, is underway in separate studies by partners at CNMI-DFW and University of Guam. The separate theoretical, modeling, and genetic studies will be coordinated to the extent possible to achieve the maximum combined benefits to understanding regional connectivity.

Work Plan

Five major tasks for accomplishing project goals are listed below. A one-year project is anticipated. This task list serves as a road-map for project implementation. For each task we provide a summary description, list of critical subtasks, and anticipated dates of completion. Project collaborators should refer to and modify this list of tasks and planned outcomes periodically to ensure that expectations are met as the project evolves.

List of Tasks

1. Refine project work plan with partners
    a. Identify research questions
    b. Define study extent
    c. Setting spawning source sizes
    d. Select key species
    e. Define spawning seasons
    f. Select larval life history parameters of interest
    g. Select key preliminary model outputs
2. Conduct drifter analysis
    a. Download and format drifter data
    b. Characterize currents
    c. Validate current vectors and set realistic diffusion values in hydrodynamic model
    d. Summarize sources and destinations of drifters passing through Marianas
3. Conduct larval connectivity modeling
    a. Download and format current vector data
    b. Run models in particle tracker
    c. Tabulate results from life history scenarios in GIS
4. Complete Draft Report
    a. General oceanographic characterization
    b. Calculate connectivity matrices to address research questions from 1a
    c. Produce source/destination summaries by island and MPA
5. Develop final digital products
    a. Provide draft products for review
    b. Revise and distribute final products
6. Training for future connectivity studies (PENDING TRAVEL FUNDING)
    a. Identify desired capabilities of Mariana partners
    b. Create graphic user interfaces and/or write procedure protocols
    c. Train Mariana staff on software and interpretation

Detailed Description of Tasks

Task 1: Refine project work plan with partners
Completion date: January-February 2013

This work plan seeks to achieve consensus among partners on general project components and approach. A series of meetings/briefings in CNMI and Guam with interested groups was conducted in January and February 2013 to acquaint the partners, show preliminary findings, create a list of local needs, and build relationships between collaborators (see Meeting Summary Notes attached). This task is based on those discussions and follow-up communication with project partners. Key sub-tasks in this phase of the project include:

a. **Identify research questions**: Through discussions with local managers and scientists the following list of key questions was compiled. Note that not all items discussed during the meetings can be addressed due to time and funding constraints. Every effort will be made to include topics that were requested by multiple partners. Time permitting,

additional topics may be addressed once the highest priority items are completed. In addition, the training component (Task 6 below) will be designed to enable Mariana partners to independently conduct a range of future investigations not addressed in the current study.

1. **What are larval sources and destinations for each of the islands/seamounts in the Mariana Archipelago?** Results can be summarized in connectivity matrices at varying scales including by island, island chain, latitudinally, or by biogeographic region. Analyses will seek to contrast connectivity among larval traits including pelagic larval duration (10, 20, 30, 40, 50, 75, 100 days), mortality rates (min., mode, and max. or mode and interquartile range from literature), and sensory zones (9, 18, 36 km buffers around settlement habitat). This will enable a broad range of taxa to be "looked-up" in the resulting suite of connectivity matrices according to their larval life-history. We will explore the possibility for beginning simulations bi-monthly given the potential for year round spawning.
2. **What are larval sources and destinations for each MPA?** Which MPAs may provide the greatest larval return? The small size of most MPAs relative to the scale of the hydrodynamic model (9 by 9 km grid cells) will be a constraining factor. This analysis will be based only on those grid cells encompassing MPAs and focus on them as starting and ending points. A range of life history parameters and seasons will be investigated as in topic 1.
3. **How do weather and climate patterns such as the Southern Oscillation, season, and typhoons influence ocean currents in the region?** Drifter data will be used to measure the influence of various factors on size, speed, and heading of regional currents.
4. **What are the sources and destinations of larvae for key taxa?** (see below)
5. **Do modeling results agree with those from genetics or other empirical studies of connectivity?** Results from existing genetics literature will be compared to simulation outputs for corresponding larval history traits. In addition, model outputs will be used to guide development of new hypotheses for genetic studies and increase efficiency of sampling design for tissue samples and plankton tows (preliminary discussion underway with CNMI-DFW and UoG).
6. **Potential additional question:** Climate change. We can mathematically reduce current vector velocities in the hydromodel to reflect reduced currents predicted due to climate change (provided that specific reduction values are available). This would involve re-running some of the above using the modified hydrodynamic model.

b. **Define study extent**: The study will center on the islands and shallow seamounts of Mariana Archipelago but will also include adjacent island neighbors that are likely to serve as sources and destinations of regional larvae and will place Mariana reef communities into context. The study area will be rectangular (longer east-west than north-south) due to the expected influence of the North Equatorial Current and may include all or parts of Wake Is., Marcus Is., Caroline Islands, Marshall Islands, Bonin and Volcano Islands, and the Philippines. Islands will be grouped depending on size and interisland distances.

c. **Setting spawning source sizes**: Spawning populations will be scaled in two ways based on discussion with partners. First, for simulations involving the entire study region, the number of virtual larvae in each HYCOM grid cell will be scaled to area of potential reef habitat. Because bathymetry is the only surrogate universally available for all islands, "potential reef ecosystem area" has been defined as 0-150 m depth to encompass mesophotic coral ecosystems. Seamount/banks of key interest have been requested in Guam and will be for CNMI. Next, for the Mariana Islands only, NOAA's Coral Reef Ecosystem Division has conducted standardized estimates of fish and coral abundance. These can be used to further scale larval production based on abundance of specific taxa.

d. **Select key species**: As requested by local partners, a number of priority species will be addressed in specific simulations. These will include rabbitfish, goatfish, and carangid

recruits, bluespine unicorn, COTS, trochus, sea cucumbers, marine algae, and ESA listed hard corals that are a high priority in the Marianas (contacted DEQ on 2/11 for prioritized coral list). Additional fish taxa (e.g. some large bodied parrotfish, emperorfish) may be added for consideration (contacted DFW and DAWR for requests 2/11). Successful modeling for all will depend on adequate knowledge of larval duration and spawning dates.

e. **Define spawning seasons**: Annual synchronous/mass spawning events for corals will be one focus of transport simulations. For hard corals this is in the June – August time period with a major pulse 1 week after the full moon in July. Discussions indicated that there are no known seasonal spawning aggregations for reef fish. The strength and timing of recruitment pulses for rabbitfish, goatfish, and juvenile carangids will be the focus of another series of analyses. Using peak catch (creel records requested from CNMI-DFW) as end dates of transport we will explore the approach of back-calculating start dates for simulations based on larval durations. We will seek to determine if strength and timing of recruitment pulse can be linked to transport phenomena. A similar approach will be used to examine recruitment pulses of COTS, corals, and other taxa of interest for which recruitment dates are available. Additional spawning periods or year-round spawning (bi-monthly may be sufficient) may also be of interest as there is some seasonal variability in the North Equatorial Current and North Equatorial Counter Current.
f. **Select larval life history parameters of interest**: A range of values for pelagic larval duration, daily mortality, and sensory/swimming capabilities will be used for some simulations. This will enable a variety of taxa to be investigated, facilitate understanding of the tradeoffs in life history parameters on transport, and enable the understanding of connectivity patterns to shift in response to climate change (e.g. shorter larval duration due to warmer waters). Specific taxa will also be focused on as noted above provided that their larval life-history parameters are known.
g. **Select key preliminary model outputs**: Connectivity matrices, proportion of self-seeding versus reliance on external larvae, contribution of each island and MPA to the regional larval pool, source/destination summaries by island, MPA, or sampling site of a genetic study, separated by life history parameters all may be desirable end products and can be produced from the transport simulations. A range of optional products will be presented to partners as preliminary results become available and most appropriate final products can be determined.

Products:

- Summary of meeting notes (attached)
- Work Plan (2nd draft complete, this document)

Task 2: Conduct drifter analysis
Estimated completion date: April 2013

This task is based on the >1500 surface drifters that have passed through the study region since 1990 from the NOAA Global Drifter Program. Whereas the hydrodynamic modeling component of the project is a computer simulation, the drifter dataset represents actual movements of ocean currents and will be used to characterize currents, validate model vectors, adjust model diffusion to a realistic value, and to understand the pathways of drift to, from, and within the Marianas that have actually occurred. NOAA will conduct all analysis in this task and provide results to local partners for review.

a. **Download and format drifter data**. COMPLETE
b. **Characterize currents**. Drifter data will be assigned several variables to facilitate characterization of ocean currents. Location relative to the archipelago (e.g. east vs west, north or south of Saipan), known current fields (North Equatorial Current), and timing (relative to the Southern Oscillation, season, and presence/absence of typhoons) will be investigated. UNDERWAY

c. **Validate current vectors and set realistic diffusion values in hydrodynamic model**. A random subset of latitudinal and longitudinal current vectors at 1000 locations will be sampled from the drifter data. The magnitude of these vectors will be compared to the corresponding date/location of velocity vectors in the hydrodynamic model using linear regression and slope comparison (1:1 slope would indicate perfect correspondence). This will provide a measure of how well the model currents correspond to actual currents on a daily timescale. To evaluate longer timescales, monthly drifter paths and headings will be overlain onto plots of average monthly current vectors from the hydrodynamic model and evaluated for agreement. To identify an appropriate level of random variability in the model vectors, to simulate sub-grid scale eddies in the hydrodynamic model, drifter paths will be compared to preliminary model runs conducted with a range of diffusion values. Diffusion values that best match drifter trajectories will be used for subsequent simulations.
d. **Summarize sources and destinations of drifters passing through the Marianas.** Because the drifters essentially mimic the passive phase of transport for marine larvae they can be used to achieve an initial understanding of the possible transport pathways of arriving at the Marianas, departing the Marianas, and even 'self-seeding' routes of departure and return. COMPLETED

Products:

- Geodatabase of drifter data
- Current characterization
- Transport summary for drifters passing through the Marianas

Task 3: Conduct larval connectivity modeling
Estimated completion date: July 2013

This task gathers the necessary datasets, builds the analytical framework, and runs the raw simulations of transport needed to quantify connectivity. The work will be facilitated by 5 high performance computers with dual Intel Xeon X5690 3.46 GHz hex-core processors and 24 GB RAM that can quickly handle the enormous amounts of data generated in this process. This phase will be done entirely by NCCOS. Key sub-tasks in this phase of the project include:

a. **Download and format current vector data.** The Hybrid Coordinate Oceanographic Model (HYCOM) is a three dimensional hydrodynamic model with a horizontal resolution of 1/12 degree (approximately 9 by 9 km grid cell size), and 1 day time step. The surface/mixed layer of HYCOM (surface to ~10 m depth) will be used to map the currents in the Mariana area and to model the movement of passive particles or "virtual larvae" of corals, invertebrates, reef fish, and algal material. Nine years of model data are available for the study region. COMPLETED
b. **Run models in particle tracker.** Simulations will be done in the General NOAA Operational Modeling Environment (GNOME). Simulations will be conducted for multiple years, seasons, and starting periods according to the scope defined in Task 1.
c. **Tabulate results from various scenarios in GIS.** Results from GNOME are then analyzed using custom ArcGIS scripts according to each combination of life history characteristics or hypotheses decided upon in Task 1. Tabulated results are used to prepare all connectivity products.

Products:

- HYCOM hydrodynamic current model files
- Geodatabase of GNOME outputs
- Tabulated results for each island or MPA by life history variables or taxon specific hypotheses from task 1

Task 4: Complete Draft Report
Estimated completion date: Sept 2013

Using the drifter analysis and tabulated outputs from Task 2-3 a suite of draft products will be created including all maps and figures as well as descriptive text. This package will be developed in consultation with island partners and when complete will constitute a first draft of the report. Chapters of the report may be organized by: 1) description of currents, 2) interisland connections, 3) MPA connections, and 4) taxa of interest. Key sub-tasks in this phase of the project include:

a. **General oceanographic characterization.** Statistics for current speed, direction, and seasonal properties will be completed based on drifter data. Modeled currents will be used to map the main current patterns in the Mariana study area. Descriptive text will summarize the key oceanographic features and any drifter paths that could be analogous to larval sources, destinations, or self-seeding of Mariana communities.
b. **Calculate connectivity matrices to address research questions from 1a.** Matrices will be produced using the outputs from ArcGIS analysis. One set of matrices will be produced for each combination of larval life history parameters and for specific taxa. Key patterns of connectivity will be described based on these matrices.
c. **Produce source/destination summaries by island and MPA as specified in Task 1.** Additional figures, maps and text will be used to identify important sources and destinations of larval connectivity by island and life history parameters. Connectivity for specific taxa of interest will be presented in separate maps and figures.

Products:
- First draft of report

Task 5: Develop final digital products
Estimated completion date: December 2013

The draft report will be revised based on peer review and final products created. A final meeting in the Marianas should occur in Fall/Winter 2013 to present the results of the study, deliver the final report, data and software, conduct training sessions (see next task), and discuss future projects. Subtasks include:

a. **Provide draft products for review.** The draft report will be made available to island partners, other local agencies, and subject matter experts for review. A list of questions will be provided to reviewers to obtain feedback on specific areas of the analysis.
b. **Revise and distribute final products.** Reviewer comments will be dealt with by NCCOS and island partners. Resulting modifications to the draft report and responses to reviewers will be recorded in track changes.

Products:
- List of reviewer comments and responses
- Final geodatabase of model outputs and drifter data
- Final Report

Task 6: Training for future connectivity studies (PENDING TRAVEL FUNDING)
Estimated completion date: December 2013

Several island partners have expressed interest in extending their ability to investigate transport phenomena beyond the duration of this study. This includes staff from CNMI-DEQ, Univ. of Guam Marine Lab, Guam BSP-CMP, and Guam DAWR. Training will cover use of hydrodynamic models and ArcGIS processing of the model outputs. This can be streamlined through the use of

customized graphical user interfaces and ArcGIS Toolboxes. The potential needs of CNMI and Guam for self-sufficiency in future analyses were discussed during initial project scoping and will be further refined through interactions with project partners during analysis phases of the project. Preliminary discussions with interested groups suggest that two half-day training sessions would be required to cover the needed topics. TRAVEL FUNDING TO SUPPORT THIS TASK WILL BE SOLICITED FROM CRCP.

a. **Identify desired capabilities of island partners.** Initial discussions took place during project kickoff meetings and it was determined that both the GNOME and ArcGIS tallying phases of the analyses are of interest.
b. **Create graphic user interfaces and/or write procedure protocols.** Exact specifications TBD.
c. **Train Mariana staff on software and interpretation.** Training will occur during the product delivery/training trip at the end of the project. Two, half day training sessions are anticipated. Topics may include, loading of HYCOM into GNOME and setting drift parameters, creating starting locations for virtual larvae and loading into GNOME, running and saving model outputs, importing results to GIS, running and modifying ArcGIS scripts and user interface to simulate specific phenomena of interest (e.g. combinations of particular life history characteristics), and transferring those results into map or graphical outputs for interpretation.

Products

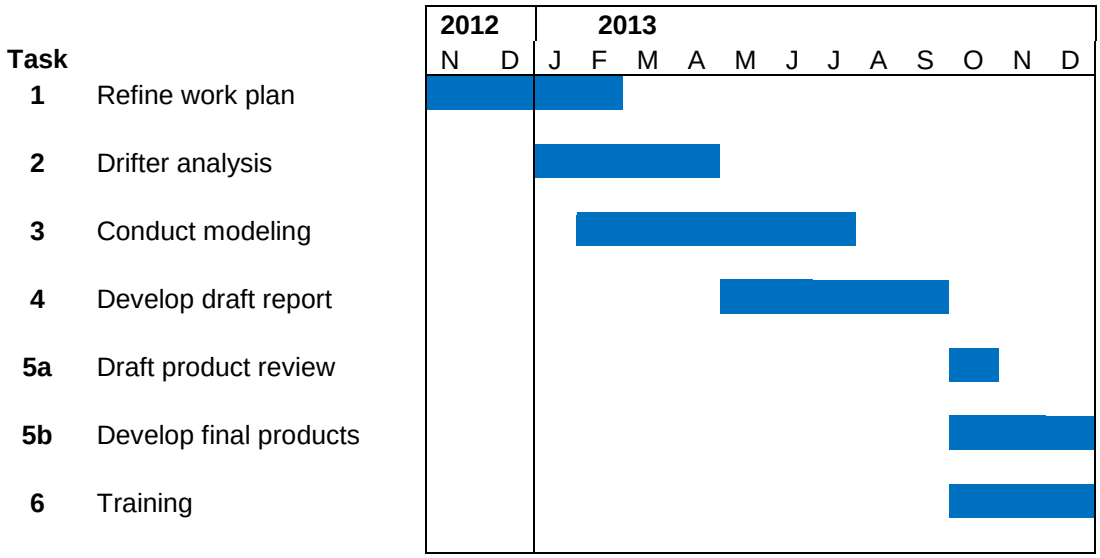
- Custom software interface TBD
- Training components TBD

NEXT STEPS:

Mariana and CRCP partners should review this SECOND DRAFT description of tasks and provide comments to NCCOS (matt.kendall@noaa.gov). Following this, NCCOS Biogeography staff will modify as appropriate and finalize the project work plan with an updated set of tasks and timeline for completion.

Project Schedule

A one-year project is anticipated. The estimated project milestone dates are approximate but will be modified depending on the final work plan.



Two site visits are anticipated, one each at the beginning (conducted Jan/Feb 2013) and end (Date TBD depending on funding and partner schedules) of the project.

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