TITLE PAGE

The Central and Northern California Ocean Observing System: Information solutions to power healthy and prosperous oceanic, coastal and estuarine communities

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I. PROJECT SUMMARY

The Central and Northern California Ocean Observing System: Information solutions to power healthy and prosperous oceanic, coastal and estuarine communities

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Society increasingly depends on timely information for decision-making to support public safety, well-being and sustainable economic growth. In the Central and Northern California region, more than 26M people rely on ocean and weather information. Shipping, fisheries, tourism and recreation are pillars of a Blue Economy that have the potential to double between 2010 and 2030, when powered by information solutions enabling sustainability. Societal focus areas include prediction of ocean weather and climate variability and change, safe and efficient transportation and commerce, risk reduction for coastal communities, and sustaining healthy ecosystems and water quality. Addressing these issues requires *in situ* observations, modeling and improved information delivery of many marine phenomena including: ocean warming and marine heatwaves, acidification and hypoxia, harmful algal blooms (HABs), sea-level rise and flooding, managing protected species and habitats, growing fisheries and aquaculture trade, vessel navigation, offshore renewable energy, and search and rescue.

The Central and Northern California Ocean Observing System (CeNCOOS), covering over 600 miles of coastline, was established in 2004 to address these challenges. We work closely with the Southern California Ocean Observing System (SCCOOS) to address needs in California and beyond. We propose a new program to align our efforts with evolving drivers and stakeholder needs to deliver a more efficient, timely, reliable and useful observing system. As one of 11 Regional Associations of the US Integrated Ocean Observing System (IOOS®), CeNCOOS is a

certified Regional Information Coordination Entity (RICE) with a governance and management structure that is comprised of five subsystems:

1. ***Governance and Management*:** Improve the reach and effectiveness of CeNCOOS through coordination, partnership, engagement and excellence.
2. ***Observations*:** Observe coastal and ocean physical, biogeochemical, biology and ecosystem variables to meet regional stakeholder needs.
3. ***Data Management and Cyberinfrastructure (DMAC)*:** Streamline access to information, including through a publicly accessible Data Portal.
4. ***Modeling and Analysis*:** Access to improved models and other analyses to scale information from individual observations and to make data relevant for policy and management.
5. ***Engagement and Products*:** Engage marine stakeholders to drive the creation of integrated information products that are valuable for decision-making.

CeNCOOS employs a 'systems approach' to information handling across the full data 'life cycle' that extends from the collection of observations to data management and product development, through to delivery of information to end-users. We coordinate a broad network of collaborators to expand the set of physics, biogeochemistry, biology and ecosystem variable observations collected from a comprehensive set of platforms, sensors and models. Our proposal includes two prospective levels of funding: *Tier 1* at $3M/yr and *Tier 2* with an additional $3M/yr.

***Tier 1* will include:**

- Maintain CeNCOOS Program Office;
- Operations and maintenance of:
  - 31 high-frequency radars (HFR), with recapitalization of 7% of our infrastructure;
  - Three glider lines;
  - 15 Coastal Observing Network stations;
  - Four HAB sampling sites;
  - Zooplankton, bird and ship sampling;
  - Elephant seal and shark tagging.
- DMAC & regional data assembly center;
- Hindcast, nowcast and forecast models with new biogeochemistry and biology outputs;
- New high-resolution coastal nowcasts in Monterey Bay with ~160 m grid cells;
- >250 data products including new support for kelp cover, climate, fisheries, marine protected areas and aquaculture indicators;
- Engagement activities to support the above including product development, and working with IOOS Association in better serving underrepresented communities and building a diverse workforce.

***Tier 2* will also include:**

- Broader recapitalizing aging assets including:
  - 35% of our HFR infrastructure, and sensor systems at 19 Coastal Observing Stations;
  - Five 'Spray 2' gliders and one Seaglider;
  - Sensors for 19 shore stations and moorings.
- HAB sampling at five stations, with Imaging FlowCytobot providing near real-time data;
- eDNA sampling on the Trinidad Head line, ACCESS, and at five HAB sampling sites;
- Nitrate and pH sensors for all our gliders;
- Zooplankton imaging on one glider and on ACCESS program ship stations;
- Uncrewed aerial system surveys for kelp; HABs, forage fish, and marine mammals,
- Passive acoustic monitoring of marine mammals and anthropogenic sound;
- Increased shark and seal tagging and a West Coast acoustic tag data accumulation node;
- New products for maritime operations, tuna, Dungeness crab and zooplankton abundances;
- Improving equity in access to information including underserved communities.

Partners: In addition to collaborators, we have many partners that assist in the delivery of our vision and mission, and/or are stakeholders with whom we work to deliver solutions. These include our *Governing Council* and CeNCOOS-SCCOOS *Joint Strategic Advisory Committee* members and more (JSAC; Tables I1-3, and I5; Letters of support, Appendix K).

II. PROJECT DESCRIPTION

A. Background ***1. The Challenge -*** California's coastal economy is a critical component (~80%) of the state's $3.1T economy (5th largest globally, 2019), much of which supports wages and jobs.[1] But, rapidly changing conditions jeopardize these valuable economic sectors.[2,3] Such conditions also pose human and ecosystem health concerns and impact food supplies, tourism and public health and safety.[4,5] Ocean temperatures are increasing in relation to climate change.[6,7,8] Persistent marine heatwaves, such as the warm 'Blob' and the Northeast Pacific Marine Heat Wave of 2019 (NEP19), and intense El Niños are wreaking havoc on our coastal ecosystems.[9-12] Kelp habitats are in precipitous decline threatening sea otters, and fisheries of abalone and red urchin.[11,13] Harmful algal blooms (HABs) are becoming more frequent, causing fisheries closures and imperiling human health.[5,14-18] Ocean acidification and hypoxia, exacerbated by upwelling of low-pH, low-oxygen water to our coasts, are exceeding global rates of change and threatening ecosystem services.[6,19-23]

2. Who we are - CeNCOOS addresses the region's societal challenges as one of 11 Regional Associations (RAs) of the US Integrated Ocean Observing System (IOOS®). Our vision is a healthy and prosperous California coastal ocean powered by information solutions. The mission is to translate data into action through the production, curation, and delivery of high-quality ocean information. The CeNCOOS region, extending 600 miles from Point Conception north to the California-Oregon border, covers some of the world's most spectacular yet imperiled coastline. Since its establishment in 2004, CeNCOOS has built a foundation based on the best available science and collaborative partnerships. We provide near continuous coverage of surface currents along the coast from 31 high-frequency radar (HFR) stations, oceanographic section data from three continuous glider line transects, more than 15 shore stations and moorings, and integration with >250 other data products (i.e. data layers) in the CeNCOOS Data Portal. Model assimilated CeNCOOS observations underpin high-quality ocean and atmosphere forecasts, nowcasts and hindcasts, all of which serve as a record for understanding the causes and consequences of natural and anthropogenic change. We support high-resolution meteorological forecasts with the Coupled Ocean / Atmosphere Mesoscale Prediction Systems (COAMPS), high-resolution nowcast and forecast of changing conditions with the California Regional Ocean Model System (CA ROMS) and three decades of hindcast data and nowcast information with the West Coast ROMS.[24-26] We sustain a vibrant partnership with the Southern California Coastal Ocean Observing System (SCCOOS) to address California's statewide requirements.

3. Connection & Benefits to End-Users & Stakeholders

a. Partnerships power CeNCOOS **-** From observations to end-user application, CeNCOOS relies on its many contributors to meet the demand for information. Our process is to work closely with state, regional, national, tribal and international groups to identify, develop, and deliver information products useful for decision-making and improving ocean stewardship - including research, analysis and education to strengthen and support all levels of ocean policy formation and application. Marine stakeholders are critical to the continuous improvement of services. CeNCOOS uses a cyclical approach to: 1) tailor engagement to identify specific user needs; 2) design and refine data products with stakeholders for specific end-user requirements and styles of interaction and delivery; and 3) iterative engagement with users to be responsive to changing needs and ensure data products remain relevant.[27] CeNCOOS Subsystems, or strategies, are advanced through teams of partners, end-users and stakeholders. The Governance Subsystem drives interactions and activities to strategic objectives and delivery for our focus areas (see Fig. I1).

Strategies are advanced by teams of investigators and partners who interact with end-user and stakeholder groups, such as at workshops and roundtable events for product scoping.

b. Drivers of the System **-** CeNCOOS delivers services to an extensive network of stakeholders and end-users. We address societal needs and challenges by pursuing shared missions and interests, producing and delivering IOOS Core Variable data and integrating information from our many investigators and partner organizations.

i. Regional and State Focus - CeNCOOS and SCCOOS address the needs of the California Ocean Protection Council (OPC), a policy body within the California Natural Resources Agency, as well as the California Ocean Science Trust (OST), a nonprofit organization that assesses scientific consensus and advises OPC. Other agencies using our data include California Departments of Fish and Wildlife (CDFW), Public Health (CDPH) and Water (CDW). California state priorities include safeguarding coastal and marine ecosystems, biodiversity and communities in the face of climate change, including marine protected area (MPA) management, stressors from marine heatwaves, ocean acidification, hypoxia and deoxygenation, HABs, kelp loss, whale strikes, whale and sea turtle entanglement, marine debris and advancing social equity. We work with tribes along California's coast, particularly the Wiyot Tribe and Tolowa Dee-ni' Nation, to strengthen observing capability at Dulawat Island and Smith River stations respectively, enriching our collective understanding of marine waters and promoting sustainability principles.

ii. West Coast Synchronization - CeNCOOS, SCCOOS and the Northwestern Association of Networked Ocean Observing Systems (NANOOS), contribute to the West Coast Ocean Alliance (WCOA) and West Coast Ocean Data Portal (WCODP), as well as the California Current Integrated Ecosystem Assessment (CCIEA), California Current Acidification Network (C-CAN), California Cooperative Oceanic Fisheries Investigations (CalCOFI), Western Association of Marine Laboratories (WAML), the US Climate Alliance, Pacific Coast Collaborative (PCC), Pacific Coast Federation of Fishermen's Associations, Pacific Coast Shellfish Growers Association (PCSGA) and many other efforts. We share information on changing conditions with Federal partners through NOAA West Watch, a quarterly teleconference. These West Coast efforts, along with a nascent *West Coast Biological Observing System* concept, are helping to advance multi/interdisciplinary observing at a pan-regional level.

iii. Federal & National Context - As a regional association of IOOS, CeNCOOS supports many NOAA programs within the National Ocean Service (NOS), National Marine Fisheries Service (NMFS) and other offices to advance common missions. Partnership examples include working with the National Centers for Coastal Ocean Science (NCCOS) to advance HAB research, monitoring and prediction, the Office of National Marine Sanctuaries (ONMS) to monitor and document changes to ecosystem conditions, and programs within Oceanic and Atmospheric Research (OAR) to foster research-to-operations transitions. CeNCOOS champions national initiatives through regional and national prioritization setting, facilitated partnership and high-quality deliverables. We spearhead the region's collection and integration of data to cover all IOOS Core Variables except ice distribution (Table I3), including contributions to national and international glider and surface current mapping networks.[28-30] CeNCOOS is a major contributor to the US Marine Biodiversity Observation Network (MBON, e.g. Central California MBON project) and US Animal Telemetry Network (ATN, e.g. supporting tagging and hosting the national ATN Data Coordinator). We work with the Ocean Acidification Program (OAP) to co-develop information for shellfish aquaculture, ONMS and many others to support their missions. CeNCOOS supplies data to track the status and trends of many variables to support Condition Reports (CRs) for the Greater Farallones, Cordell Bank and Monterey Bay National Marine

Sanctuaries (GFNMS, CBNMS, MBNMS). Examples of our work to bring advanced technologies and methods from research to operations include contributions to the Ocean Technology Transition (OTT) and Coastal and Ocean Modeling Testbed (COMT) initiatives. Successful transitions include operationalizing ocean acidification and hypoxia (OAH) observing applications in aquaculture and the Imaging FlowCytobot system (via OTT), as well as the California Harmful Algae Risk Mapping (C-HARM) model, and advancing the West Coast Operational Forecast System (WCOFS) model through assessment, model development, and ecological products (via COMT). Our glider data are assimilated into atmospheric river predictions to inform management by the Bureau of Reclamation, Army Corps of Engineers, and California state agencies. Moreover, California has committed to 100% renewable energy by 2045 and offshore wind is considered a critical component of the renewable power grid. Our observations and models contribute to analysis of wind farm call areas of the Bureau of Ocean Energy Management (BOEM), ecological forecasting initiatives of the National Aeronautics and Space Administration (NASA), search and rescue efforts of the US Coast Guard (USCG) and operations of the US Department of Defense (DOD).[e.g. 31]

iv. Global Benefit - CeNCOOS is a regional leader within the Global Ocean Observing System (GOOS) through coordination, service, and engagement. CeNCOOS serves as a critical coordinator of individual investigators in forming IOOS, a Regional Alliance of GOOS. The interconnected nature of the ocean demands this regional-to-global approach. For example, CeNCOOS works with the Global Ocean Monitoring and Observation Program (GOMO) office of NOAA to bridge observations from the coast to the open and deep ocean, e.g. through glider observations, data integration, data-assimilative models, and integrated products that span and connect multiple scales. CeNCOOS investigators lead regular contributions to the Deep Ocean Observing Strategy (DOOS), Global Ocean Acidification Observing Network (GOA-ON), Group on Earth Observation Biodiversity Observation Network (GEO BON), Animal Borne Ocean Sensors (AniBOS) and more to standardize and share observational data and ensure best practices.[32-35] Most recently, this included CeNCOOS investigator leadership in the *International Virtual Conference on the Use of Environmental DNA (eDNA) in Marine Environments: Opportunities and Challenges* hosted by the Partnership for Observing the Global Ocean (POGO). Such efforts contribute to achieving the goals of the UN Decade of Ocean Science for Sustainable Development (2021-2030), the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), which are also priorities of regional stakeholders.

c. Focus areas **-** CeNCOOS provides information solutions to solve the region's most pressing challenges. We integrate information from 11 federal agencies, seven state agencies, and a wide array of data providers, platforms, and technologies. We bring diverse resources and expertise to collect, reuse, and add value to a wide array of observations. Driven by regional needs, CeNCOOS advances four societal focus areas:

i. Predicting Weather & Climate Variability & Change - CeNCOOS observing systems provide sustained observations for the status and trends of ocean weather and climate over scales from minutes to decades. This includes atmosphere (COAMPS) and ocean (CA ROMS) forecasts, such as for the members of the trade-focused Marine Exchange of the San Francisco Bay Region and northeast Pacific DOD operations. CeNCOOS tools provide weather and climate-driven ocean acidification and nutrient upwelling estimates to support NOAA CCIEAs.[36] Observations and modeling are supporting assessment of change in CA (MPAs) for CDFW and our three NOAA National Marine Sanctuaries. We estimate variation and change by providing place specific time-

series data from satellite, *in situ* observations from CeNCOOS and our partners, and from models at local, state and West Coast level. We provide products for three National Marine Sanctuaries, and over 100 MPA and 500 reference sampling sites in CA. We support the NOAA Ocean Acidification Program and others to optimize observing ocean acidification in our region, driving system evolution, and better constraining error in our biogeochemical ROMS modeling.

ii. Safe & Efficient Transportation & Commerce - CeNCOOS provides surface current and trajectory maps, models, and analysis products for emergency response to California Oil Spill Response and Prevention (OSPR), the General NOAA Operational Modeling Environment (GNOME) of the NOAA Office of Response and Restoration, and the Search and Rescue Optimal Planning System (SAROPS) of USCG. We also engage municipalities to share capabilities and expand use, such as with the Office of Emergency Services in Marin County. Our capability operates through an automated system of surface current (HFR) observations and related model predictions to guide response efforts and reduce search time (e.g. during the Cosco Busan oil spill in San Francisco Bay). These surface current estimates are also used in recreational boating (e.g. the San Francisco Bay Yacht Club using our *BayCurrents* app being updated now), and Point Reyes and Mendocino freedivers using our CeNCOOS Data Portal.

CeNCOOS observations and data, including HFR, glider, and modeling outputs enable decision-making needed for an expanding Blue Economy. CeNCOOS data are vital to the CCIEAs, which supported NOAA management of $507M in commercial landings value for the West Coast in 2019. Moreover, CeNCOOS fosters long-standing partnerships with shellfish growers to co-develop observations and information to guide decision-making in aquaculture operations, an industry that generates ~$500M/yr across the West Coast.[37] We continue to improve access to information for shellfish growers, fishery managers, and fishers to include integration of biogeochemical and biology data and processing into decision support tools that address their needs. Offshore wind development and sea-level rise are growing issues in our region. Our data supports decision-making for these issues through integrated data for environmental impact assessment and infrastructure adaptation in response to sea level rise.

iii. Preparedness & Risk Reduction for Coastal Communities - CeNCOOS data and products support readiness and resilience to climate change and coastal hazards in the region by providing federal, state and municipal programs with state-of-the-art data, tools, training and expertise. CeNCOOS resources advance planning and response to storms, accidents and public or ecosystem health threats (i.e. litter, microplastics, pollutants, pathogens and HAB toxins). For example, CeNCOOS, SCCOOS, and others collaborate to collect California Harmful Algal Bloom Monitoring and Alert Program (HABMAP) samples and data, and to produce the California HAB Bulletin, as well as observations and modeling to support C-HARM forecasts of HAB species and toxin.[38] HAB events have had widespread impacts on marine life and fisheries in California, such as the 2015/16 HAB event that led to a ~$100M loss to fisheries landings and high mortality of protected species.[39,40] HABMAP data are critical for CDFW, California's Office of Environmental Health Hazard Assessment (OEHHA) and other regulators to safeguard human and wildlife health. CeNCOOS also conducts OAH and HAB monitoring at aquaculture facilities to co-develop information for industry operations and risk management including with the Hog Island Oyster Co. and Monterey Abalone Company, as well as managers such as CDPH and OEHHA.[41,42]

iv. Healthy Ecosystems & Water Quality - CeNCOOS supports dynamic ecosystem management by integrating diverse types of information to document cumulative impacts of many marine stressors including overfishing, pollution, habitat destruction, and global-scale environmental change under a holistic framework. CeNCOOS observations and information

products inform on warming, storm intensity, and species distribution and abundance to support policy and management to foster kelp recovery.[13] Our coastal observing data and indicators support many applications including California's climate change assessments and Ocean Health Dashboard and report card.[43] CeNCOOS' tagging efforts with elephant seals and white sharks serve as sentinel indicators that readily respond to change and can highlight when, where, and how changing conditions are impacting biological systems.[44,45] Working with state and academic partners, we integrate large sets of biology and ecosystem data such as the BeachWatch and BeachCOMBERS citizen surveys of seabird and mammal strandings, the Multi-Agency Rocky Intertidal Network (MARINe) with more than 180 sites along the CA coast, and the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) program surveys. These data are used to create visualization tools for managers to assess MPAs, Sanctuaries and other region-specific data from these programs alongside other data from numerous other sources.

4. The Opportunity - There is great potential to further evolve CeNCOOS efforts to support a growing Blue Economy, while also sustaining natural resources and habitats for future generations. Critical gaps remain that, if filled, could deliver more effective integrated, easy-to-use information solutions for managing sustainable growth. Indeed, CeNCOOS observations, DMAC, modeling and information products provide the backbone for tracking the rapid changes to marine ecosystems and resources.

a. The Blue Economy **-** The Organisation for Economic Co-operation and Development estimates that California's $45B Blue Economy will double between 2010 and 2030.[3] Nonetheless, every aspect of California's ocean economy is vulnerable to increasingly warm and hazardous conditions.[1] CeNCOOS provides critical information that underpins sustainable growth by harmonizing with, and contributing to, regional-to-global efforts. CeNCOOS is preparing industry and managers with more effective information to predict and assess impacts with greater spatial and temporal resolution. Such focused application improves outcomes for fisheries, shipping, and tourism, while also protecting people, habitats and marine life.

b. Implementing a West Coast Biological Observing Network **-** CeNCOOS, together with NANOOS and SCCOOS, is implementing a *West Coast Biological Observing Network* to coordinate biological observations and deliver the information necessary to understand the ongoing changes in our marine ecosystems. We are transforming biological observing in IOOS in order to effectively address the many regulatory demands for biology and ecosystems data (e.g. Magnuson-Stevens Act, Marine Mammal Protection Act, and California Ocean Protection Act). Biological data are complex and delivered through diverse techniques and providers, making coordination, harmonization and integration very challenging. However, regional, national and global initiatives have marked both *the need* for linking biological observing with physics and biogeochemistry, and *the capability* to do so with coordinated best practices and delivery of very valuable information for decision-making (e.g. MBON, ATN, AniBOS, and GEO BON). As with global and national bodies, a key recommendation in our region by the CA Ocean Acidification and Hypoxia Science Task Force is to "better connect chemical and biological monitoring."[33-31,46] This lack of joint '*physical-biogeochemical-biological*' observing is our biggest gap.

The California Current Large Marine Ecosystem (CCLME) is well studied. However, additional coordination and investment will optimize investment and pan-regional interoperability and address this joint '*physical-biogeochemical-biological*' observing gap. A substantial component of our *Tier 2* activities are focused on delivering a vision for a coordinated, collaborative *West Coast Biological Observing Network*, including many components at CA or West Coast level. This vision follows from a large workshop: *U.S. West Coast SCCOOS* •

CeNCOOS • NANOOS - ATN • MBON • OTN Biological Observations Workshop Summary Report: Identifying Regional Needs and Priorities for Animal Telemetry and Biodiversity Observations of Aquatic Species in 2018 and subsequent engagement in 2019-2020.[47]

The maturation of several observing and machine-readable formatting and metadata, efficient data processing technologies presents a great opportunity to fill these gaps by producing information solutions with true biology and ecosystem-level information required by stakeholders. We propose to support the evolution of ecosystem indicators by transitioning several observing technologies and data handling methods into our operations. Photographic and acoustic imaging of phytoplankton and zooplankton, passive acoustic monitoring, eDNA and other genomic characterization of marine community change, animal telemetry, uncrewed aerial systems (UASs), and artificial intelligence (AI)/machine learning (ML) tools to process this information, are all poised to expand and improve our ability to address stakeholder needs. For example, the use of the Imaging FlowCytobot (IFCB) system in an early warning system for HABs with SCCOOS is transforming HAB observing capabilities across the state.[16] Likewise, we will advance ecosystem forecasting by leveraging advances of WCOFS and improvements in the North Pacific Ecosystem Model for Understanding Regional Oceanography (NEMURO, West Coast ROMS-based).[48]

B. Goals & Objectives - *The CeNCOOS Approach* - CeNCOOS addresses societal challenges by applying a 'systems approach' that manages data throughout the entire lifecycle, from collection to end users. We actively engage stakeholders to understand priorities, needs and gaps to guide our work. We collect feasible and impactful observations and ensure the data meets standards for data quality and is curated to make information readily available for onward use. This includes processing through (semi)automated analytics, modeling and data products, and providing information to end-users in useful formats. This systems approach is applied in part through documenting the flow of information through data stream plans and conceptual flowcharts that highlight relationships between policy, management and priority setting, and their application to ocean observing practices, information handling and the evolution of information provision for users in application-specific decision-making. MBON work has augmented this approach to be fully inclusive of biological observing and related end-user perspectives (Fig. I2). As a NOAA-accredited Regional Information Coordination Entity (RICE), CeNCOOS meets federal standards for data handling, including the application of FAIR data principles (Findable, Accessible, Interoperable, and Reusable; see *Data Management Plan*). The function of a RICE in integrating information is essential; it allows for inclusivity, transparency, and trust in exchanging information that connects investigators and partners to end-users and stakeholders. It thus enables CeNCOOS to use the power of 'big data' to solve challenges in sustaining our marine resources. CeNCOOS implements five strategic subsystem goal areas:

1. ***Governance & Management*:** Improve the reach and effectiveness of CeNCOOS through coordination, partnership, engagement, and excellence.
2. ***Observations*:** Observe coastal and ocean physical, biogeochemical, biology, and ecosystem variables to meet regional stakeholder needs.
3. ***Data Management & Cyberinfrastructure (DMAC)*:** Streamline access to information, including through a publicly accessible Data Portal.
4. ***Modeling & Analysis*:** Access to improved models and other analyses to scale information from individual observations and to make data relevant for policy and management.
5. ***Engagement and Products*:** Engage marine stakeholders to drive the creation of integrated information products that are valuable for decision-making.

Our Work Plan provides detailed objectives, most of which have continuous delivery over each year of the award. Deviations from this 'ongoing' mode are noted in the Work Plan and detailed *Milestones Schedule* (see Appendix E).

C. Work plan - Here we present a work plan that applies this cyclical engagement approach to deliver impact. This proposal has two tiers: *Tier 1* - $3M/yr and evolves our work to an improved system of similar scale to our current operation, and *Tier 2* - $3M/yr ($6M/yr total) that fully recapitalizes our system and advances the *West Coast Biological Observing Network*, addressing our joint '*physical-biogeochemical-biological*' observing gap.

***Tier 1* will include:**

- Maintain CeNCOOS Program Office;
- Operations and maintenance of:
  - 31 high-frequency radars (HFR), with recapitalization of 7% of our infrastructure;
  - Three glider lines;
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- DMAC & regional data assembly center;
- Hindcast, nowcast and forecast models with new biogeochemistry and biology outputs;
- New high-resolution coastal nowcasts in Monterey Bay with ~160 m grid cells;
- >250 data products including new support for kelp cover, climate, fisheries, marine protected areas and aquaculture indicators;
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***Tier 2* will also include:**

- Broader recapitalizing aging assets including:
  - 35% of our HFR infrastructure, and sensor systems at 19 Coastal Observing Stations;
  - Five 'Spray 2' gliders and one Seaglider;
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- HAB sampling at five stations, with Imaging FlowCytobot providing near real-time data;
- eDNA sampling on the Trinidad Head line, ACCESS, and at five HAB sampling sites;
- Nitrate and pH sensors for all our gliders;
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- Uncrewed aerial system surveys for kelp; HABs, forage fish, and marine mammals,
- Passive acoustic monitoring of marine mammals and anthropogenic sound;
- Increased shark and seal tagging and a West Coast acoustic tag data accumulation node;
- New products for maritime operations, tuna, Dungeness crab and zooplankton abundances;
- Improving equity in access to information including underserved communities.

Our decision-making and work plan development is guided by key principles including that: 1) Existing time-series are prioritized and sustained to enable tracking and understanding of changing conditions; 2) Networks of co-located physical-chemical-biological observing assets can be achieved through leveraging state and federally funded efforts; 3) Data integration is essential to standardize data, build access pathways and ensure utility; 4) Additional effort is required to scope and downscale modelled information for coastal users and to include to biology and ecosystems information; and 5) Information products require sustained investment. This is guided by our *CeNCOOS Strategic Plan (2020-25)*, *Framework for Decision-Making*, NOAA RICE-certified CeNCOOS *Standard Operating Procedures* (SOPs) and *Data Stream Plans* (https://www.cencoos.org/organization-overview/documents/). Our framework importantly enables event response, which includes redirecting assets such as HFR antenna stations, gliders or moorings to spill areas, or creating *ad hoc* data streams and data products to support specific needs including plume and spill tracking (e.g. for buoyant, passive or sinking material).

1. Governance & Management Subsystem:

The CeNCOOS Program Office is a small, technically trained team housed at MBARI, which includes the CeNCOOS Director (Ruhl), Program Manager (Harper), the Data and Information Manager (Daniel) and the Product Developer (Bahr). The Program Office works closely with our DMAC lead (Bochenek, Axiom Data Science) to implement the DMAC subsystem. Program risks are managed through consultation and prioritization with our Governing Council (GC). This includes instances of funding shortfalls, urgent requests, deficiencies in uptime and overload in DMAC and product maintenance. Risks associated with timely delivery to end-users will also be managed through Portal feedback and analytics, and engagement activities and other metrics to understand needs and how well they are being met.

Our 15-person GC holds the final decision-making authority in CeNCOOS. The Council consists of at least two members from these balanced categories, as well as three at-large seats: Academic and/or research organization; Industry or for-profit corporation; Federal government; State government; Local, regional, or tribal government or agency; and Nonprofit organizations. CeNCOOS also maintains advisory committees, task teams, and working groups aligned with our drivers and focus areas (e.g. teleconferences of HFR, Coastal Observing Network, HABMAP, MPAs, OAH, glider and modeling teams). A Joint Strategic Advisory Committee, (JSAC) administered with SCCOOS, guides our state-level efforts. CeNCOOS will:

- Provide regional leadership and coordination through hosting and attending meetings (e.g. GC, Science Impact, IOOS Association, Ocean Sciences), community workshops (e.g. bringing observing and modeling experts together with end-users for applications including understanding ocean acidification and managing marine spaces) and roundtable meetings (e.g. convening local stakeholders, such as in relation to water quality) [**Obj. 1.1**, MBARI].
- Improve coordination and strengthen collaboration with national, tribal, regional, state, local, and industry entities via meetings, website, outreach and engagement, including through our GC membership, as well as engagements that bring such different groups together around specific issues [**Obj. 1.2**, MBARI].
- Manage fiscal and programmatic administration including an annual descoped work plan and simi-annual progress reporting, annual program/subsystem review, as well as a mid-term RICE recertification [**Obj. 1.3**, MBARI].
- Sustain and build partnerships to improve observing system impact including through aligning and documenting issues, solutions, resources, and writing grant proposals to augment our impact and excellence [**Obj. 1.4**, MBARI, et al.].
- Seek new partnerships to reach diverse communities and make every stage of the data creation and sharing process more relevant, accessible, and equitable [**Obj. 1.5** MBARI, see also **Subsystem 5**]. This will include a strategic development meeting in Y4, as well as soliciting Expressions of Interest to evolve our system.
- Enhance the Program Office capacity in ***Tier 2*** with additional staff support for project management, as well as data and information management.

2. Observations Subsystem:

HFR - Goal 2.1, Tier 1 **-** CeNCOOS and SCCOOS sustain California's world-leading *surface current mapping network*, providing vital data for USCG SAROPS, CA OSPR operations, boaters, shipping and other activities. This robust network forms nearly continuous spatial coverage along the California coast with data assimilated into our California ROMS (Fig. I3, I4) following operations and maintenance practices of the Radiowave Operators Working Group (ROWG).[29]

Advancements from the CeNCOOS region include drone-enabled aerial calibrations (Cal Poly), national technology and software upgrades (CODAR), SF Bay 'plume tracker' and *BayCurrents* application work (UC Davis). Support will continue for 27 existing CeNCOOS stations, and four former SCCOOS sites. The 31 HFR sites will operate with >90% uptime (84% in 2019), as well as recapitalize 7% of our infrastructure [**Obj 2.1.1**, CODAR, UC Davis, NPS, Cal Poly].

HFR - Goal 2.1 Tier 2 - Aging infrastructure and continuous exposure to harsh coastal conditions requires investment to avoid outages. With 11 radars being more than 16 years old, we will improve and recapitalize 35% of our aging infrastructure and harden the network for system resilience [**Obj. 2.1.2**, CODAR, UC Davis, NPS, Cal Poly].

Coastal Observing Network - Goal 2.2, Tier 1 - The CeNCOOS Coastal Obs. Network, which consists of automated shore stations, coastal moorings, and ship stations, as well as many collaborator and partner stations that are contributed in kind, provides observing infrastructure for documenting change and variability in the region.[49-51] We will continue to improve the quality and consistency of our observations for understanding both short-term variation (weather) and long-term changes (climate) in temperature, salinity, ocean currents, acidification, dissolved oxygen, nutrients and HABs. This will include work to:

- Operate 15 stations and moorings from Trinidad Head to Morro Bay, as well as funding for the seasonal collection of zooplankton, sea bird, turtle and mammal species/abundance data as part of the Applied California Current Ecosystem Studies (ACCESS) cruises, as well as nominal support to integrate many other collaborator and partner stations (see Fig. I3, I6) [**Obj. 2.2.1**, Cal Poly, MLML, UCSC, Cal Mar, SFSU, UC Davis, HSU, Pt Blue].
- Expand the Coastal Obs. Network to grow our *ocean acidification and hypoxia observing network* capability to support aquaculture in Morro, Monterey, San Francisco, Tomales, and Humboldt Bays, along with contributions from SCCOOS (site-by-site issue areas are in Table I4) [**Obj. 2.2.2**, Cal Poly, MLML, UCSC, MBARI, SFSU, UC Davis, HSU].

Coastal Obs. Network Enhancements - Goal 2.2, Tier 2 - We will address our joint '*physical-biogeochemical-biological*' observing gap. This addresses recommendations from the CA OAH Taskforce, OAP research, and CA MPA monitoring program, HABMAP Steering Committee, and others we propose to make Coastal Obs. Network enhancements to:

- Conduct statewide OAH observing in kelp forest MPA habitats at Point Arena, Van Damme, Point Buchon, and Big Creek with additional sites in SCCOOS [Fig. I6, **Obj. 2.2.2**, Reef Check, UCSC, MBARI, with SCCOOS].
- Deploy three moorings in kelp forest MPA areas on the Monterey Peninsula providing data on waves, and depth profiles of temperature and dissolved oxygen in relation to monitoring kelp cover [**Obj. 2.2.1**, Stanford].
- Upgrade aging equipment through recapitalization, to ensure data quality and system reliability [**Obj. 2.2.3**, Cal Poly, MLML, UCSC, SFSU, UC Davis, HSU] including integrating advanced technologies including YSI/Xylem EXO2 multiparameter sondes, self-calibrating SeapHOx sensors, fluorometers, profilers and telecommunication systems [*Del. 2.2.3.1*. SFSU, Cal Poly, MLML, UCSC, HSU, UC Davis].
- Fill data gaps by initiating additional time-series in San Pablo Bay, Mendocino and Big Sur (Granite Canyon), areas of high variability and uncertainty with diverse stakeholder requirements [*Del. 2.2.3.2*, SFSU, Noyo Center, UC Davis, Cal Mar].

HABs - Goal 2.2, Tier 1 - The CCLME is experiencing increasingly frequent, large and long-lasting HABs related to warming conditions, resulting in fisheries closures and seeding a new 'hotspot' in Northern California.[52] As a key contributor to HABMAP, CeNCOOS will:

- Maintain four shore-based HAB monitoring stations: Monterey Wharf, Santa Cruz Wharf, Bodega Marine Lab and Trinidad Head. HABMAP samples are analyzed for phytoplankton species identification and abundance, domoic acid toxin concentration, and limited nutrient concentration. And, deploy Solid Phase Adsorption Toxin Tracking (SPATT), following methods of Kudela et al. (2015) and the HABMAP Steering Committee (https://calhabmap.org/).[53] [**Obj. 2.2.4**, UCSC, HSU, UC Davis, MLML, with SCCOOS].
- Contribute to the California HAB Bulletin, together with SCCOOS and our HABMAP collaborators. This provides local-scale information to alert managers of changing conditions to reduce closure days while protecting public and wildlife health. Bi-Weekly emails conveying near-real-time HAB occurrences are provided to commercial and recreational fishing organizations, OPC, CDFW, OEHHA, and other registered managers.

HABMAP Expansion with HABON - Goal 2.2, Tier 2 **-** We will add one HABMAP site in San Francisco Bay, a highly populated area with recreational shellfish harvesting [Fig. I6, **Obj. 2.2.4**, UCSC, HSU, UC Davis, MLML, Cal Poly, UCSB, UCLA, USC, UCSD]. In cooperation with SCCOOS, we will develop methodology and best practices as part of the Prevention, Control and Mitigation of HABs (PCMHAB) program, and accelerate access to HAB information via operating the new California IFCB network and the related California HAB Observing Network supporting NCCOS (HABON) [**Obj. 2.2.5**, UCSC, MBARI, HSU, UC Davis, with SCCOOS]. HABON work will include capability to distinguish offshore/onshore dynamics of toxin production, a gap in managing HAB-related closures.[16,54]

Gliders - Goal 2.3, Tier 1 - CeNCOOS operates a fleet of ocean-going autonomous gliders to provide near real-time observations of subsurface and open-ocean physical, chemical, and biological processes and drivers in the California Current. CeNCOOS gliders provide critical sub-surface data for model assimilation and are used to predict OAH variability, climate anomalies, atmospheric rivers, marine heat waves, and drought (e.g. via the Western Regional Climate Center). We join SCCOOS as part of the California Underwater Glider Network to supply data on temperature, salinity, phytoplankton, turbidity, ocean currents and more, covering a structured array of ocean section lines along the coast (0 to ≥500 m depth), and supply data for assimilation into modeling hindcasts, nowcasts and forecasts.[30,55,56] We will continue to operate three continuous glider transects [Fig. I3, **Obj. 2.3.1**]. This includes Seaglider operation on the Trinidad Head line jointly with NANOOS [*Del. 2.3.1.1*, OSU], and Spray glider operations on the Pt. Arena and Monterey lines [*Del. 2.3.1.2*, UCSD] with logistics support for Pt. Arena from UC Davis [*Del. 2.3.1.3*] and Monterey from MBARI [*Del. 2.3.1.4*].

Glider Recapitalization with Biochemistry and Biology - Goal 2.3, Tier 2 **-** CeNCOOS is operationalizing a new generation of technologies with improved capabilities. We will:

- Recapitalize gliders on each line (One Seaglider and four Spray 2 systems, with NANOOS recapitalizing one Seaglider for the Trinidad line) [**Obj. 2.3.2**, UCSD, MBARI, OSU].
- Expand biogeochemical and biological observing capacity [**Obj. 2.3.2**, UCSD, MBARI, OSU, Farallon] by employing maturing Deep-sea DuraFET pH sensors and a new miniaturized generation of the *In Situ* Ultraviolet Spectrophotometer (ISUS) nitrate sensor to include the collection of acidity and dissolved nutrients variable data across the entire CeNCOOS-SCCOOS glider fleet [*Del. 2.3.2.1*, MBARI, OSU, UCSD, with SCCOOS].[57,58]
- Build on the successful demonstration of glider-based plankton imaging, and integrate a 'Planktivore' camera together with pH, nitrate and other sensors on a glider for seasonal use in quantifying zooplankton abundance [Fig. I6, *Del. 2.3.2.2*, MBARI, UCSD, with

SCCOOS].[59] Such joint glider observations directly address our '*physical-biogeochemical-biological*' observing gap, contributing to the *West Coast Biological Observing Network*.

Animal telemetry - Goal 2.4, Tier 1 **-** CeNCOOS supports tagging of top predators for managing the CCLME and other marine spaces including CA State Parks, MPAs, Sanctuaries and BOEM offshore wind call areas [**Obj. 2.4.1**, shark tags, *Del. 2.4.1.1*, Stanford; elephant seals, *Del. 2.4.1.2*, UCSC]. CeNCOOS satellite tags now return data via the Global Telecommunication System (GTS) to assimilate into many models including ours.[45] Elephant seal tags profile gradients expanding from the coast to the subtropical gyre providing robust oceanographic data including temperature, salinity, phytoplankton via chlorophyll-a (Fig. I7a). Shark satellite and acoustic tagging provides oceanographic sentinel data on top predator responses to changing conditions, as well as estimating distribution and abundance to satisfy CCLME and Sanctuary CR needs and their work with local municipalities to manage the steadily increasing white shark incidents near beaches (Fig. I7b).[60,61]

Animal Telemetry and Data Assembly Expansion - Goal 2.4, Tier 2 **-** We will expand seal and white shark tagging and build data access pipelines to characterize the northeast Pacific warm pool phenomena, as well as its connection to coastal variation in our region [augmenting *Del. 2.4.1.2*, UCSC]. Demands for this information in the NANOOS and SCCOOS regions are also driving the need to more systematically track and communicate information from sharks and other acoustically tagged animals. We will work with ATN and others to establish and operate a West Coast Acoustic Data Assembly Center Node for Animal Tracking, contributing to the *West Coast Biological Observing Network* and linking open-ocean and pan-regional change [*Del. 2.4.1.3*, Stanford, with NANOOS and SCCOOS].

Uncrewed Aerial Systems - Goal 2.4, Tier 2 **-** UASs with color and multispectral cameras offer extraordinary potential to collect data quickly and efficiently. Here we will transition UAS information delivery from research to operational collection across physical, biogeochemical, and biological variables [**Obj. 2.4.2**, MBARI, UCSC, UC Davis, Cal Poly]. These systems collect information on temperature, waves, ocean color, and species and/or abundance information on phytoplankton, zooplankton, forage fish, submerged aquatic vegetation (kelp, seagrass), sea turtles and marine mammals. We will operate these UASs to conduct monthly surveys in the Bodega, Monterey Bay and San Simeon areas covering from shore to line of sight limits offshore (sometimes extended by small vessel support). End-user benefits include meeting needs for MPA management, the GFNMS and MBNMS CRs, as well as informing UAS operation policy for ONMS and advancing the NOAA UAS Strategy.[62]

eDNA - Goal 2.4, Tier 2 **-** CeNCOOS is establishing one of the first repeat environmental DNA (eDNA) monitoring programs in IOOS. eDNA is proving to be an effective tool for low-cost, high-resolution solutions for biodiversity observing. MBON results have shown their effectiveness.[63-65] This capability extends from marine microbes to forage fish, top predator fishes and marine mammals that are otherwise impractical to assess.[65] We will build on the work of the Central California MBON to sample and sequence eDNA. Samples will be collected and processed seasonally on the Trinidad Head Line, ACCESS cruises and HABMAP program stations [**Obj. 2.4.3**, MBARI, HSU, Pt. Blue, UC Davis, SFSU, UCSC, MLML]. This will contribute to the NOAA 'Omics Strategy and a statewide eDNA initiative, in cooperation with SCCOOS, to deliver support for CCIEAs, Sanctuaries CRs and CA HABMAP Bulletin goals, also contributing to the *West Coast Biological Observing Network*.[66]

ACCESS Plankton Imaging - Goal 2.4, Tier 2 **-** Plankton imaging is maturing with a miniaturized and reduced cost system.[67] We will deploy this profiling camera system at the ACCESS cruise stations delivering information on total suspended matter and zooplankton species/abundance. [Fig. I5, **Obj. 2.4.4**, Pt Blue, Axiom, MBARI], which will also be collecting zooplankton tows. Combining net tow, eDNA and imaging-based quantification will provide high quality biodiversity data to couple with ongoing OAH observing in ACCESS and elsewhere, addressing our joint '*physical-biogeochemical-biological*' observing gap, contributing to the *West Coast Biological Observing Network*, and satisfying CCIEA and Sanctuaries CRs requirements for phytoplankton, zooplankton, and OAH indicators.

Passive Acoustic Monitoring - Goal 2.4, Tier 2 **-** We will conduct passive acoustic monitoring via hydrophones in contribution to the Ocean Sound Observation Network (OSON) of the West Coast. [Fig. I8, **Obj. 2.4.5**, NMSF, NPS, UCSD, MBARI, with NANOOS and SCCOOS]. The coastal ocean is becoming increasingly noisy with deleterious effects on marine life and important implications for managed spaces and species, military activities, offshore wind permitting and other industrial operations. Passive acoustic monitoring (PAM) is a cost effective way to detect and measure change, identify and reduce coastal hazards, vessel traffic noise, as well as environmental change in temperature, fish, invertebrate and marine mammal species variables.[39] This builds on SanctSound, which has developed and tested post-processing codes and automated routines for giving comparable data outputs from multiple regions. This also complements a *Topic 2* Proposal from this call (PAM Access Network, PI: CW Bell). With two stations supported by CeNCOOS, and 12 others supported through a combination of NANOOS, SCCOOS and others, OSON will meet the needs of NMFS, ONMS, NPS, and the Office of Naval Research (ONR), contributing to the *West Coast Biological Observing Network*.

Fishing Vessels of Opportunity - Goal 2.4, Tier 2 **-** Commercial fishing vessels provide unique opportunities to observe environments where target species occur. Sensors on fishing gear are well suited to provide profiles and rare bottom observations in fishery habitats. This approach, used elsewhere, is proving to be a cost-effective, on-shelf complement to Argo data, linking coast to open ocean phenomena.[68,69] We will collect temperature and salinity data co-located with catch data through a new California Fishing Vessels of Opportunity Program operated jointly with SCCOOS and NANOOS [**Obj. 2.4.6**, ODN, with SCCOOS and NANOOS]. In CeNCOOS, this will focus on equipping a vessel in each of the valuable Dungeness crab and squid fisheries. Importantly, it also improves engagement with the fishing industry, as well as providing data for the *West Coast Biological Observing Network* and assimilation into models and onward use by fisheries managers in CDFW and NMFS.

3. DMAC Subsystem:

CeNCOOS DMAC capability and quality is world leading. The CeNCOOS DMAC subsystem, operated and maintained by Axiom Data Science, utilizes tools covering the entire data lifecycle, from data collection, to long-term preservation, to discovery and reuse. We support integration across many sources into our Portal, such as ~750 sensor station feeds in our region including from the Coastal Data Information Program (CDIP) and Federal agency data on atmosphere, stream, estuary and ocean conditions, as well as state and regional data from Caltrans, PISCO, MARINe and many others. Our DMAC operations are made more responsive and resilient through reducing human intervention needs. This includes machine-to-machine data transfer to support model nowcasts and forecasts, as well as our full data catalog being accessible through our Portal. For example, our key emergency response capability requires no intervention from Program Office

staff, where our data are automatically available to emergency response agencies including USCG and CA OSPR via tools including SAROPS and GNOME. Our *Data Management Plan* follows the NOAA Environmental Data Management Framework.

Cyberinfrastructure - Goal 3.1, Tier 1 **-** CeNCOOS cyberinfrastructure manages and visualizes high-volume, heterogeneous, observation data from hundreds of sources. The DMAC system automates the ingestion of real-time observations from *in situ* devices, model and remote-sensed outputs, and mobile platform data, and caches millions of observations each week in fast, high-availability memory. This approach ensures we follow recommended and standard practices of the IOOS DMAC committee to meet the core capacity requirements for IOOS RAs.[71] Data collected by CeNCOOS investigators and partners are distributed on the web-based CeNCOOS Data Portal (https://data.cencoos.org/) and DAC. This is managed according to best practices identified by NOAA under the CeNCOOS RICE Certification. To achieve this we will:

- Support physical hardware (i.e. data center with high-performance computing) and software systems (application program interfaces) that support data ingestion, search, aggregation, access/transport and storage/archive systems.
- Maintain compatibility with cloud tools, providing the ability to scale to any size project, advancing the NOAA Cloud Strategy[70], e.g. with imaging or acoustic data.
- Operate and maintain DAC hardware and software capacity infrastructure repair and replacement, model evolution and troubleshooting [**Obj. 3.1.1**, Axiom, MBARI].
- Maintain data storage hardware for data streams and backed-up through physical storage media in preservation-oriented data formats (e.g. netCDF4, flat IEEE binary, ASCII, HDF, GRIB, and GIS formats) [**Obj. 3.1.2**., Axiom].
- Increase the robustness of our DMAC system to maintain high uptime performance and improve fault tolerance for ingestion, visualization and data services [**Obj. 3.1.3**, Axiom].

FAIR Data Practices - Goal 3.2, Tier 1 **-** Our DMAC capability will:

- Maintain data access services, as required by IOOS, through a variety of standard services (e.g. OPeNDAP, WCS, WFS, WMS and in a variety of common formats including CSV, MATLAB, and JSON). These services are provided by a combination of THREDDS, ERDDAP, and GeoServer. We provide technical assistance to investigators and partners, including through the Research Workspace [**Obj. 3.2.2**, Axiom, MBARI].
- Give access to the Research Workspace, an Axiom-developed platform that enables research teams to securely share datasets, author and execute server-side code, generate metadata, and publish data products with Digital Object Identifiers (DOIs) to national repositories within the DataONE network, the NOAA National Center for Environmental Information (NCEI), and National Data Buoy Center (NDBC).
- Conduct additional processing of regional and national modeling products by Axiom to allow for fast data exploration and visualization, as well as for metadata enhancement, cataloging, and distribution through CeNCOOS data services.
- Prioritize new data sets for ingestion for display through the CeNCOOS Data Portal, including new streams. Our work with maturing biological and ecosystem data types strengthens stewardship through data transfer, standardization, documentation, visualization, and archival steps [*Del. 3.2.1.3*, Axiom, MBARI].
- Serve datasets through the portal with metadata conforming to the Federal Geographic Data Committee (FGDC) and/or ISO standards and applying additional IOOS supported standards as they become fully developed, such as Darwin Core and Biological Data Services. All these

efforts facilitate the efficient maintenance, troubleshooting and refresh of existing data streams, sources and metadata [**Obj. 3.2.3**, Axiom, MBARI].

Implementing a California Ocean Observing Portal - Goal 3.3, Tier 1 **-** CeNCOOS is leading the establishment of a state-wide '*California Ocean Observing Portal*' in partnership with OPC and SCCOOS to meet state-wide requirements for a single pathway to access priority data. This involves rebranding our Portal interface, expanding data holdings, and enhancing analysis and product features. The CeNCOOS Data Portal already integrates diverse data types in >250 data product layers including 1239 sensor streams from across the state, capable of handling all IOOS Core Variables. This already includes SCCOOS HFR, CA ROMS, data from the California Cooperative Fisheries Investigations (CalCOFI) and is expanding to include additional statewide HABMAP and MPA monitoring program data [**Obj. 3.3.1**, Axiom, MBARI, with SCCOOS].

Data Visualization Enhancements - Tier 1 & 2 **-** We are improving visualization capacity to better assess physical, chemical, biological and ecosystems data from diverse platforms including imaging, acoustics, animal tags and genomic-based methods in partnership with MBON, ATN, ONMS, NMFS, OPC and others [**Obj. 3.3.2**, Axiom, MBARI]. Portal visualization updates also include optimization of the *Curated Data View* tool to improve layout, data layer handling, download options, improved sharing, custom management accounts, implementing custom map tools, including drawing shapes, measuring distances, making annotations, and introduction of user-defined export or printing of annotated maps, charts, or images [**Obj. 3.3.3**, Axiom]. For example, we will build on advancements made by the SanctSound project and the prototyping of a plankton DAC as part of HABON IFCB and other plankton imaging initiatives to deliver easy-to-understand visualizations.

Data Visualization Improvement Processes - Goal 3.6, Tier 1 **-** We deliver curated information products to provide value-added translations to ensure data reaches stakeholders in relevant, useful formats. Axiom will work closely with data suppliers and end-users to implement prioritized user products, tools and web interfaces [**Obj. 3.6.1**, Axiom, MBARI et al.], which includes developing product requirements [*Del. 3.6.1.1*]; beta testing and refining products in order to increase their utility; developing work plans with measurable timelines, deliverables, and performance metrics [*Del. 3.6.1.2*]; and assisting with the development of proposals.

Data Quality - Goal 3.4, Tier 1 **-** CeNCOOS follows standardization and quality assurance practices, quality control procedures, including from the Quality Assurance/Quality Control (QA/QC) of Real-Time Oceanographic Data (QARTOD) system. We liaise with expert organizations for standards and sharing including GOA-ON, Ocean Gliders, AniBOS, GEO BON and ROWG [Axiom, MBARI]. This includes maintaining the automated pipeline for applying QARTOD checks and visualizations to real-time data feeds streaming into the Portal, following the QARTOD GitHub library (github.com/ioos/ioos_qc). We make test results available for download within the data and metadata, and visually within the Portal.

Data Archival - Goal 3.5, Tier 1 **-** CeNCOOS and partner data continues to be archived at trusted repositories, e.g. NCEI and the Ocean Biodiversity Information System (OBIS). We will:

- Maintain automated upload of observation data to NCEI [**Obj. 3.5.1**, Axiom].
- Maintain transmissions of data to NDBC as needed, including migration to providing observations to NDBC via ERDDAP [**Obj. 3.5.2**, Axiom].
- Maintain archival pathways for recovered or post-processed data and metadata to NCEI, DataONE and OBIS, via the Research Workspace [**Obj. 3.5.3**, Axiom].

Engagement with Data Providers - Goal 3.7, Tier 1 **-** Axiom will work with CeNCOOS to engage stakeholders on DMAC issues through linkages including CeNCOOS and DMAC meetings, workshops, and roundtable discussions. Axiom provides portal user support by tracking and responding to 100% of feedback and data requests [**Obj. 3.7.1**, Axiom]. Additional activities will include addressing new and existing requirements of the IOOS DMAC community and other affiliated organizations [**Obj. 3.7.2**, MBARI, Axiom], participating in IOOS DMAC related workgroups and meetings [*Del. 3.7.2.1*, Axiom], and assist in DMAC related proposals that further the CeNCOOS vision and mission [*Del. 3.7.2.2*, Axiom].

Supporting New Data Integration, Goal 3.8, Tiers 1 & 2 **-** We will streamline access to information on emerging, high-priority issues and from additional observing platforms through improved data portal functionality. *Tier 1* efforts include: the Multivariate Ocean Climate Index (MOCI), new kelp satellite data products, evolutions of the Coastal Observing Network, HFR and glider data streams [**Obj. 3.8.1**, Axiom, re: **Obj. 5.2.1, 5.2.2,** Farallon, WHOI et al.]. *Tier 2* includes new data streams from a SF Bay SCHISM-CoSiNE model (re: **Obj. 4.3.1**), glider pH, nitrate and zooplankton (re: **Obj. 2.3.2**), additions to Coastal Observing Network including eDNA (re: **Obj. 2.2.2-2.2.3)**, HAB monitoring advances including the IFCB (re: **Obj. 2.2.4-2.2.5)**, UAS biology and ecosystem data (re: **Obj. 2.4.2)**, ACCESS zooplankton imaging (re: **Obj. 2.4.4**), OSON data (re: **Obj. 2.4.5**), and fishing industry observations (re: **Obj. 2.4.6**) [**Obj. 3.8.2**, Axiom MBARI et al.]. *Tier 2* work will also include AI and ML tools, advancing the NOAA Artificial Intelligence Strategy.[72] Scalable computing is executed in proximity to petabytes of data and storage, analysis engines such as Apache Spark, Dask and Pangeo on compute clusters, as well as convolutional neural network (CNN) tools for AI and ML. A key benefit is that investigators can analyze extremely large datasets using HPC co-located with the data.

4. Modeling & Analysis Subsystem:

CeNCOOS supports model and analysis products from CA ROMS and West Coast ROMS, which use atmospheric boundary conditions from our COAMPS model, all of which scale individual observations to scales useful for decision-making. Model skill is supported, in part, by assimilating our HFR, glider, and animal tag data.

Atmospheric Modeling - Goal 4.1, Tier 1 **-** We will operate a regional atmospheric model (COAMPS, Fig. I9) which provides valuable forecast information for US Navy and other DOD operations, as well as ocean surface boundary conditions for our regional ocean models [**Obj. 4.1.1**, NRL].[24] COAMPS includes variables for heat flux, temperature and wind speed and direction at the ocean's surface.

CA ROMS - Goal 4.1, Tier 1 **-** We will also continue to operate CA ROMS jointly with SCCOOS, producing nowcasts and 3-day forecasts [**Obj. 4.1.2**, UCLA, with SCCOOS]. CA ROMS uses COAMPS boundary conditions and assimilates observations from HFR, gliders, floats, satellites and other sources to give 3-km resolution data including surface current speed and direction, temperature, salinity and sea-level (Fig. I9).[73] CA ROMS supports USCG SAROPS and CCLME IEA efforts, as well as waste water dischargers.[74] Importantly, we expect end-user data streams from this model will transition from CA ROMS to WCOFS by 2024, with WCOFS having similar specifications over the entire West Coast (Fig. I9).

West Coast ROMS - Goal 4.1, Tier 1 **-** WCOFS does not yet have a hindcast for assessment of change over decadal scales. Therefore, we will continue to operate West Coast ROMS with hindcast and nowcasts and integrate its NEMURO biogeochemical and ecosystem model outputs [**Obj. 4.1.3**, UCSC]. The NEMURO ecosystem model outputs include phytoplankton and

zooplankton abundance, and OAH variables.[48] This contributes to the *West Coast Biological Observing Network*, and satisfies CCLME IEA and Sanctuaries CRs requirements for phytoplankton, zooplankton, and OAH indicators.

San Francisco Bay Operational Forecast System Integration - Goal 4.3, Tier 1 -We will improve access to the San Francisco Bay Operational Forecast System (SFBOFS) model, which is operated by the Center for Operational Oceanographic Products and Services (CO-OPS). It delivers Operational tide and current information for navigation with a new forecast every six hours including water levels, water currents, water temperatures and salinity.[75] We will integrate and serve SFBOFS and other priority model outputs through the Portal and related *Curated Data View* tool [**Obj. 4.3.1**, MBARI, Axiom].

San Francisco Bay Biogeochemical Model Operations - Goal 4.3, Tier 2 - We will operate the new San Francisco Bay Semi-implicit Cross-scale Hydroscience Integrated System Model - Carbon, Silicate, Nitrogen Ecosystem (SFB SCHISM-CoSiNE) [Fig. I10, **Obj. 4.3.1**. UCLA, SFSU].[77] This model couples high-resolution physics with a comprehensive biogeochemical model. It assimilates data from our HFR network, Coastal Obs. Network and more to provide nowcast and forecast data on phytoplankton, zooplankton, acidity, oxygen dissolved nutrients and biological vital rates. This leverages investments from NASA, CA CDW and others to advance ecological forecasting strategies of NOAA and NASA and informs water management decisions in dam and barrier operation by providing products on nutrient fluxes, phytoplankton blooms, turbidity and fish migrations.[31,73,75,76]

High-Resolution Coastal Modeling - Goal 4.3, Tier 1 - Existing models perform poorly near shore, where variability is high and stakeholder needs are greatest. As WCOFS has been transitioning to operations, we have developed high-resolution nest tools within WCOFS. We will bring into operation a nested, fine-scale model in Monterey Bay building on WCOFS capability [**Obj. 4.3.3**, UCSC, MBARI]. This has two nests, Pt. Conception to Pt. Arena at 800 m resolution and Big Sur to Half Moon Bay at 160 m, providing outputs suitable for quantifying connectivity between MPAs and tracking source/sink dynamics for marine debris, pollutants, agricultural fertilizers, sediment plumes and object trajectory estimates. This work serves the needs of OPC, CDFW, MBNMS and regulatory bodies such as via the Central Coast Long-term Environmental Assessment Network (CCLEAN) to assess marine debris and pollution.

Model Advancements & End-user Engagement - Goal 4.2, Tier 1 & 2 - We will conduct end-user consultation, model expert inputs and systems analysis to define and develop data streams and lifecycle planning for new information products that take advantage of COAMPS, CA ROMS, West Coast ROMS with NEMURO and WCOFS [**Obj. 4.2.1**, MBARI, NRL, UCSC, UCLA]. We will continue to conduct outreach to scope useful products related to ocean acidification, ecosystem assessments and other valuable model outputs [**Obj. 4.2.2**, MBARI, UCSC]. We will conduct engagement on San Francisco Bay SCHISM-CoSiNE development and product outputs, including via roundtable discussions with the interagency Integrated Modeling Steering Committee for San Francisco Bay Modeling and the San Francisco Estuary Institute [**Obj. 4.2.3**, MBARI, UCLA, et al.].

5. Engagement & Products Subsystem:

We are committed to providing freely accessible, relevant, and accurate information about our ocean, coasts, and estuaries for all. To accomplish this goal, we iteratively engage end users in product development to connect observing effort to end user need (e.g. Fig. I11). We are also

working to develop more meaningful engagements with traditionally underserved and underrepresented communities including Indigenous, Chicanos/Hispanics and Black communities, other communities of color, low income and marginalized groups and those most vulnerable to climate change to understand and address their needs. Tribes and other traditionally underserved and underrepresented communities along California's coast often act as stewards of their coastal and marine environments that are the first to identify changes to local ecosystems.

End-User Products - Goal 5.1, Tier 1 & 2 **-** Using our processes for connecting benefits to end-users, CeNCOOS will utilize a 'toolbox' of product types and lead the creation of:

- *Curated Data Views* via the CeNCOOS Data Portal (e.g. for recreational boaters, local managers *Tier 1*; and underrepresented and underserved communities, *Tier 2*);
- Custom 'Port-lets' including dashboards (e.g. for aquaculture, managed spaces including MPAs, Sanctuaries, BOEM call areas, *Tier 1*; maritime operations, *Tier 2*);
- Climate and kelp cover indicator data (e.g. MOCI, kelp satellite product, *Tier 1*);
- Ocean health indicator data including for infographics including data streams for Sanctuaries and CCLME IEA (*Tier 1*), and a Zooplankton abundance indicator (*Tier 2*);
- Mobile applications (e.g. *BayCurrents, Tier 1;* tuna, Dungeness crab fishing, *Tier 2*);
- ESRI StoryMaps for storytelling outreach (e.g. science center exhibits, *Tier 2*), and;
- Bulletins and other synthesis products (e.g. Cal. HAB Bulletin, State of the Estuary, *Tier 1*).

This work will be achieved, in part, through the Program Office and Axiom product development team (*Tier 1 & 2*), as well as outside services (e.g. specialist developers; *Tier 2*) [**Obj. 5.1.3**, MBARI, Axiom, Farallon, Exploratorium, Noyo Cent., ODN, Cal Mar].

Product Usage Statistics - Goal 5.1, Tier 1 **-** CeNCOOS tracks the use of its data and information products on the CeNCOOS website [**Obj 5.1.4**, MBARI, Axiom]. Web usage statistics are published using Google Analytics, a web analytics software that tracks and logs user requests. The CeNCOOS website (https://cencoos.org) and CeNCOOS data services (ERDDAP, THREDDS, Data Portal) are enabled for analytics collection on a daily basis using a custom python script and metrics of interest. These are summarized for display on the CeNCOOS website (https://www.cencoos.org/analytics/).

Diversity, Equity and Inclusion - Goal 5.1, Tiers 1 & 2 **-** In *Tier 1*, CeNCOOS will work with the IOOS Association and the IOOS Program Office to expand and diversify the ocean, coastal and Great Lakes workforce and to provide relevant ocean and coastal data and information to underserved or underrepresented communities. We are strengthening engagement with underserved communities in *Tier 2* and will:

- Co-convene a series of meetings with these communities, including through the Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS) and California Indian Environmental Alliance [**Obj 5.1.1,** MBARI, Exploratorium, CSUMB (via SACNAS), CIEA, ODN]. Targeted community meetings will provide a venue to:
  - Communicate about the observing systems and the information currently available;
  - Gather and document priority issues, and;
  - Build teams to co-develop information products to deliver priority information in relevant formats [**Obj. 5.1.1 - 5.1.3**, MBARI, Exploratorium, SACNAS, CIEA, ODN].
- Collaborate with tribes and other traditionally underserved and underrepresented communities to initiate partnerships to share information about the observing system capabilities and gather requirements for future observations, DMAC, and information delivery [**Obj. 5.1.1**, MBARI, Exploratorium, CIEA, CSUMB, ODN].

- Organize two capacity-building workshops to provide hands-on training with local experts aimed at connecting diverse communities to ocean observing [1st in Y3, 2nd Y5, Goal 5.6, **Obj. 5.6.1**, MBARI, Exploratorium, CIEA, SACNAS, Cal Mar, MBARI, UCSD].

Fisheries Industry Engagement and Products - Goal 5.6, Tiers 1 & 2 - The California Dungeness Crab industry, the state's most valuable fishery ($51.9M in 2019), is increasingly reliant upon observational data for everyday decision-making. In particular, anomalously warm conditions in the Northeastern Pacific have caused excessive HAB events and are driving endangered blue and grey whales further inshore in search of food during the winter months. This has resulted in a record number of whale entanglement and ship strikes as whales encounter crab pots and shipping lanes.[78,79] In response, regional managers have delayed the commercial Dungeness crab season, and even cancelled recreational fishing seasons, in response to HAB events and associated anomalous conditions. In response, CeNCOOS is forging new partnerships with fisheries industry stakeholders to understand data use, gaps, and to scope and refine information solutions [**Obj. 5.6.2**, ODN, MBARI, Exploratorium]. We will also expand the dissemination of fishing support tools for CeNCOOS stakeholders including the NANOOS Tuna Fishers app and the NOAA EcoCast model outputs [**Obj. 5.3.2**, MBARI, Axiom].

Aquaculture Dashboards - Goal 5.3, Tier 1 - CeNCOOS supports the U.S. West Coast's $228M shellfish aquaculture industry through our tailored information products.[80] CeNCOOS is collaborating with several IOOS RAs to develop user-products of common interest. With NANOOS, SCCOOS, and the Alaska Ocean Observing System (AOOS), we will develop a new user-friendly port-let, the *Oyster Dashboard*. This will be customizable by RA and industry sites to incorporate data, model output or content tailored to the area and user group [**Obj. 5.3.1**, MBARI, with NANOOS, SCCOOS, and AOOS], in cooperation with Canadian-IOOS Pacific. The modular and pan-regional design of visualization will allow customization by each RA and we will incorporate new features for ease of use. This builds on success in working on shellfish growers such as via the IOOS Partners Across Coasts Ocean Acidification Data Portal (IPACOA) and will draw on *in situ* and model observations where applicable (e.g. C-HARM, WCOFS).

Maritime Operations - Tier 2 - Expanding California's $45 billion ocean economy requires state of the art decision-support tools designed to address private-sector requirements. We propose to develop collaboratively a Maritime Operations port-let, building on the success of the NANOOS Maritime Operations tool. We will work with NANOOS, AOOS, and the Pacific Islands Ocean Observing System (PacIOOS) to harmonize this capability at pan-regional level for the Pacific and will include development of new features satisfying a broader user community. We will collaborate to update and maintain our San Francisco *BayCurrents* mobile app with a focus on recreational boaters [**Obj. 5.3.1**, MBARI].

Ecosystem Indicators - Goal 5.4, Tier 1 - Changes in marine ecosystems can occur rapidly and have important implications for ecosystem structure, function and services. Environmental and ocean-health indicator products for California MPAs, NOAA CCLME IEAs, Sanctuary CRs, the State of California's Coast and Oceans Report Card and WCOA-led Ocean Health Scorecard help track changes to ecosystems and marine resources in easily digestible formats. CeNCOOS expands capability and capacity for enduring biological and ecosystem indicators through data access pathways and synthesis into useful indicators [**Obj. 5.4.1**, MBARI]. We work with resource managers and habitat expert teams to format and assemble *in situ* ecosystem monitoring data for inclusion in multi-scale *Curated Data Views* [**Obj. 5.4.2**, MBARI]. We will collaborate with

Sanctuary, MPA, and other marine space managers to provide indicator data for use in CCIEAs, Sanctuary CRs, State of California and WCOA assessments [**Obj. 5.4.3**, MBARI].

Regional Climate Indicator - Goal 5.2, Tier 1 **-** CeNCOOS indicator products include the Multivariate Ocean-Climate Indicator (MOCI) for the State of California, which tracks the primary mode of variability in coastal conditions across three distinctive regions of California's continental shelf habitats [**Obj. 5.2.1**, Farallon].[81,82]

Statewide Kelp Canopy Area/Biomass Dynamics Indicator - Goal 5.2, Tier 1 **-** Kelp forests off the coast of California are inherently dynamic systems and respond to a variety of physical and biological drivers. In order to understand how kelp responds to changing environmental conditions, researchers and managers need information showing the current status of California's kelp forest systems and how they have varied through time. Together with SCCOOS, we will deliver a statewide kelp dataset of kelp canopy area and biomass data for giant kelp (*Macrocystis pyrifera)* and canopy area for bull kelp (*Nereocystis luetkeana)* and giant kelp in near real-time (quarterly updates of kelp canopy area dynamics) along the coast of central and northern California [**Obj. 5.2.2**, WHOI, with SCCOOS].[84,85]

Zooplankton Abundance Indicator - Goal 5.2, Tier 2 **-** We will also produce a dataset for year-round understanding of zooplankton abundance in the California Current that will be provided to fisheries managers and modelers in a timely fashion. This includes the production of a zooplankton abundance indicator by combining glider acoustic Doppler current profiler (ADCP) data, CalCOFI net data, and CalCOFI acoustic data processed for krill. The model developed to relate these data products will allow the calculation of a zooplankton product that can be produced in a timely fashion and on a fine horizontal and vertical scale [**Obj. 5.2.4**, Farallon].

Dynamic Tools for Preventing Whale Strikes and Entanglements - Tier 2 **-** Managers of fisheries and marine mammals and birds rely on spatially and temporally explicit information to determine distribution and abundance.[83] Tools and indicators for dynamic management of issues including strikes and entanglements must integrate physical, biogeochemical, and biological data streams through innovative analysis and modeling. Building on initiatives of the California MPA network, NMFS and animal tagging, CeNCOOS will integrate and share data products on vessel tracking by automatic identification system (AIS), ocean noise, animal telemetry and marine mammal observations, and modeling tools to improve the Whale Watch 2.0 dynamic ocean management tool predicting whale distribution [**Goal 5.5**, MBARI].[86]

Interactive Observatory Displays - Goal 5.2, Tier 2 **-** Marine stakeholders can benefit from interaction with locally-derived scientific data. Unfortunately, ecosystem monitoring information is often not available in an easily digestible format. We will develop, adapt, and share interactive display and exhibit content including an ESRI StoryMap coupled with a live data dashboard for public display, as well as a high-resolution media wall visualization. Interactive display content will be made available through our website and displayed at select venues on an interactive kiosk (e.g. the Noyo Center for Marine Science, Greater Farallones Visitors Center, MBNMS Sanctuary Exploration Center, Exploratorium). We will co-create with stakeholders new learning experiences and data visualizations that will pair high-priority data streams from IFCBs and visual data from MPAs and citizen science groups (e.g. kelp forest canopy, Reef Check divers). Exhibit content will be available to any visitor center or museum. We will also explore strategic venues to meet new audiences including ferry terminals and tribal interpretive centers. [**Obj. 5.2.3**, Exploratorium, Noyo Center, Cal Mar].

Education and Teaching Module Coordination - Goal 5.7, Tier 2 **-** CeNCOOS data are used in higher education classrooms to provide real-world context for marine scientists, including in the California State University and University of California systems. Yet, too often, lab modules and field exercises for undergraduates using CeNCOOS data, Portal and other data services and analytical tools are not readily accessible. We will work with current CeNCOOS PIs to coordinate, share and evolve existing curriculum materials for inclusion in undergraduate courses that use observing data collected by the CeNCOOS network. These materials will be shared on the CeNCOOS.org website and shared with oceanography faculty and community colleges in the region (e.g. Diablo Valley College, San Ramon Community College, and Solano Community College) [**Goal 5.7**, Cal Mar, MBARI].

Milestones Schedule (Summary) - Work plan elements where x = milestone(s), and - = continuous activity and gray shade denotes active sub-award (*see detailed version in Appendix E*).

Work plan elements	**Year 1**				**Year 2**				**Year 3**				**Year 4**				**Year 5**			
Quarters	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1.Governance & Mgmt.	-	x -		x -	-	x -		x -	-	x -	-	x -	-	x -	-	x -	-	x -	-	x -
2.Observations	x -	x -	x -	x -	-	x -	-	x -	x -	x -	x -	x -	x -	x -	x -	x -	-	x -	-	x -
3.DMAC	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -
4.Modeling & Analysis	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -
5.Engagement &Products	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -	x -

Project Budget (Summary) - Summary budget following SF424 categories. Please see *Appendix A* for the detailed budget and related documentation, including Tier 1 & 2 portions.

Overall Budget ($)	Year 1	Year 2	Year 3	Year 4	Year 5	Years 1-5
PERSONNEL+ BENEFITS	696,830	705,868	738,101	755,284	775,895	3,671,978
TRAVEL	28,900	28,900	43,300	31,700	43,300	176,100
EQUIPMENT	110,196	240,116	140,770	134,480	142,211	767,772
SUPPLIES	145,967	164,385	176,596	185,354	171,998	844,299
CONTRACTUAL	34,000	49,000	49,000	49,000	49,000	230,000
CONSTRUCTION	-	-	-	-	-	-
OTHER	-	-	-	-	-	-
SUBAWARDS	3,932,377	3,978,362	3,976,406	3,989,432	3,925,217	19,801,794
TOTAL DIRECT COSTS	4,948,269	5,166,631	5,124,173	5,145,249	5,107,621	25,491,943
INDIRECT COSTS	725,718	523,598	533,504	536,203	546,101	2,865,124
TOTAL	5,673,987	5,690,229	5,657,677	5,681,452	5,653,722	28,357,067
Holdback items	326,013	309,771	342,323	318,548	346,278	1,642,933
FINAL TOTAL	6,000,000	6,000,000	6,000,000	6,000,000	6,000,000	30,000,000