

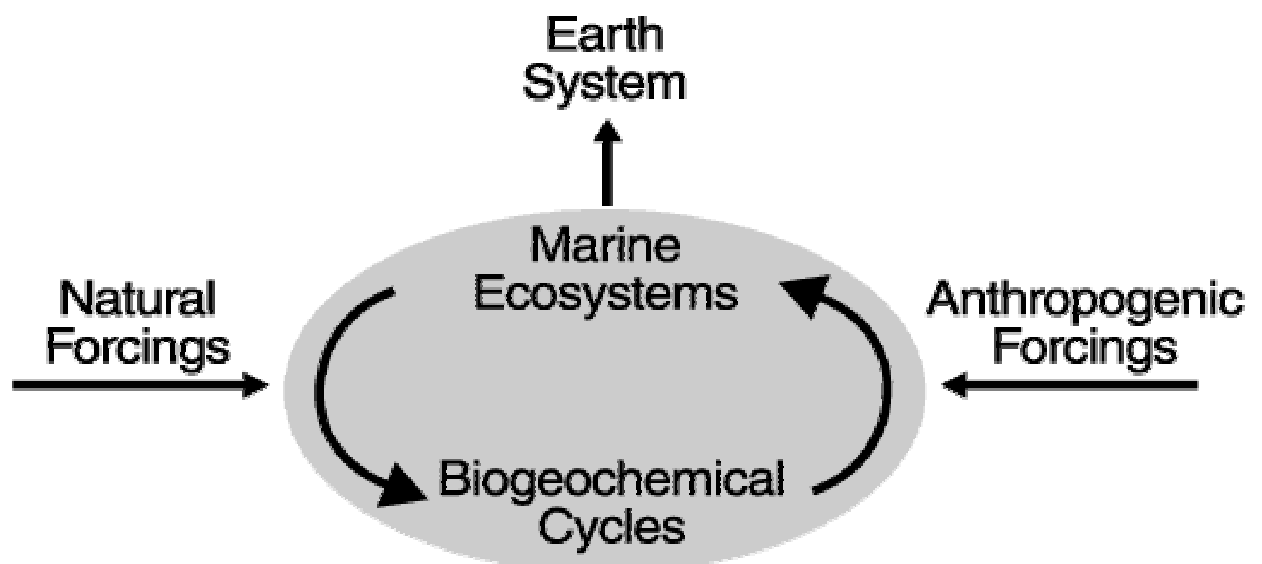
1 This document is the first draft of two key sections of the OCEANS Science  
2 Plan/Implementation Strategy. The first section is the Scope, which gives a broad overview of  
3 the OCEANS project. The second section lists the science themes and issues. This is initial  
4 draft of the key science sections of the planned document.  
5  
6

## 7 Scope of the OCEANS Project

### 8 A -Introduction

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10  
11 *How do biogeochemical<sup>1</sup> cycles, marine ecosystems<sup>2</sup>, and their interactions*  
12 *respond to global change and, in turn, feed back to the Earth System?*  
13

14 This question, depicted schematically in Figure 1, captures the essential features of the  
15 OCEANS project. It highlights the important knowledge gaps that must be filled over the next  
16 decade of research in order to meet society's need to address the challenges of global  
17 change. We must uncover the mechanisms by which marine life controls its biogeochemical  
18 environment, and how this environment in turn controls the dynamics of life. Changing  
19 environmental conditions, forced by natural and anthropogenic factors such as changes in  
20 pH associated with anthropogenic CO<sub>2</sub> invasion, and periodic climate cycles, affect these  
21 interactions. We must understand how human and natural processes and events affect the  
22 ocean in order to be able to predict the consequences of continued and increased variability  
23 and levels of forcing as a result of global change. Changes within the ocean set new  
24 environmental conditions, which in turn have consequences for the broader Earth System.  
25 Advancing our knowledge and quantification of these interactions and feedbacks is the  
26 central goal of the OCEANS project.  
27  
28  
29



<sup>1</sup> **biogeochemistry:** the definition of biogeochemistry used in this document is very broad, following Libes, S. M. (1992). *An Introduction to Marine Biogeochemistry*. New York, NY, John Wiley and Sons, Inc. Biogeochemistry is defined as "the science that studies the biological, chemical and geological aspects of environmental processes."

<sup>2</sup> **ecosystem:** "A given abiotic physico-chemical environment and its particular biotic assemblage of plants, animals and microbes comprise an ecological system or ecosystem, in which ecological kinship is demonstrated" Kormondy, E. J. (1976). *Concepts of Ecology* (2nd edition). New Jersey, Prentice-Hall 238.

48 Figure 1. Schematic depiction of the focus of the OCEANS project. Marine biogeochemical  
49 cycles, ecosystems and their interactions; variability of interactions due to both natural and  
50 anthropogenic forcings; and feedback to the Earth System.

51

52

## 53 **B – Biogeochemistry, Ecosystems and their interactions**

54

55 Our understanding of marine biogeochemical processes has progressed greatly over the  
56 past two decades, due largely to the efforts of the Joint Global Ocean Flux Study (JGOFS).  
57 We have identified and partially quantified many of the important biogeochemical processes  
58 in the ocean (e.g., carbon fluxes, nitrogen transformations, micronutrient control of biological  
59 processes). Evidence from JGOFS time-series observations suggest that impacts of low-  
60 frequency variability in the physical system (e.g., changes in stratification, circulation,  
61 ventilation, wind transport and mixing) can have major impacts on the lower levels of marine  
62 food webs and associated biogeochemical cycles. The introduction of macro- and  
63 micronutrients to the euphotic zone is controlled by physical processes, the nature of which  
64 is altered with changes in the climate system. Coastal and air-borne nutrients enter the  
65 ocean system where they affect food-web<sup>3</sup> productivity and complexity, thus impacting fluxes  
66 of the major elements. A focus of OCEANS will be the cycling of elements in the ocean and  
67 the effects of nutrients on ocean productivity.

68

69 The lower trophic levels of food webs are critical in driving marine biogeochemical cycles and  
70 through the JGOFS project we have gained a great deal of knowledge of phytoplankton and  
71 bacterial population dynamics in the euphotic zone and the effects of microorganisms in  
72 major nutrient cycles (and to some extent, iron). Yet, our understanding of some important  
73 types of marine microorganisms is limited. For example, the role of viruses in ecosystem  
74 dynamics and biogeochemical cycling—by controlling the population dynamics of  
75 phytoplankton and other organisms—remains poorly quantified; our understanding of the  
76 roles of bacteria and grazers on remineralisation of organic material in the surface,  
77 mesopelagic and deep ocean is also limited; and the predominance of Archaea deep in the  
78 water column is now recognized, but the ecological and biogeochemical roles of these  
79 organisms are unknown. Evidence for the existence of previously undiscovered bacterial  
80 and viral communities in the water column and the seafloor bring new challenges to the  
81 understanding and modelling of biogeochemical transformations.

82

83 It is now recognized that key phytoplankton groups play a significant role in controlling the  
84 quality and quantity of food for meso-zooplankton or early development stage of pelagic fish,  
85 as well as the export of organic carbon and the production of gases by organisms.  
86 Understanding, what stimulates growth of these key phytoplankton groups and controls their  
87 population dynamics is an important factor in the link between biogeochemical cycles and the  
88 higher trophic levels of the food web. Phytoplankton also affect the penetration of light and  
89 hence the heat of the ocean, and thus play a role in determining physical forcing through  
90 stratification in areas of high phytoplankton biomass. The food-web dynamics of  
91 phytoplankton populations are a key link between physics, geochemistry and other  
92 components of marine food webs. Extending our understanding of phytoplankton dynamics,  
93 particularly of key species or functional groups, will assist in predicting the potential impact of  
94 global change on marine biogeochemical cycles and ecosystems.

95

96 Studies of marine ecosystems have also shown the effects of both climate and human  
97 activity on upper trophic levels of the food web. Palaeoceanographic records indicate that

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<sup>3</sup> **food webs:** marine food webs include the species, community structure, predator-prey and other relationships among the species, and the flows of materials and energy through the food webs Keeton, W. T. (1980). Biological Science (3rd edition). London, W.W. Norton and company 1080.

98 the abundance of anchovies off California has fluctuated by a factor of 20 over the last two  
99 millennia, before commercial fishing began. At shorter time scales it has been suggested  
100 that catch trends of several pelagic and demersal fish species vary in-phase or out-of-phase  
101 with global atmospheric indices over the last 50 to 70 years. Changes in the decadal pattern  
102 of climate variability in the North Pacific region, as reflected in the Pacific Decadal Oscillation  
103 (PDO) index, are known to have caused major ecosystem disruptions and population  
104 changes, ranging from phytoplankton to fish. The recruitment of albacore tuna in the  
105 equatorial Pacific Ocean is negatively affected by El Niño-Southern Oscillation (ENSO)-  
106 dominant periods, while skipjack tuna displays high recruitment in the same region during  
107 ENSO years. The mechanisms through which climate influences upper trophic levels,  
108 however, are poorly understood, because climatic influences act directly at each level, as  
109 well as indirectly through transfers through food webs. It has also been suggested that  
110 ecosystems may have a limited number of stable states toward which they move, and that a  
111 small environmental change can cause ecosystems to shift state. Human exploitation  
112 patterns are known to cause major ecosystem changes. Selective exploitation of marine  
113 organisms can change the size and age structure of their populations. Species targeting and  
114 the excessive removal of large fish has reduced the trophic structure of several ecosystems  
115 and thus has interfered with the flow of matter within the pelagic domain and between the  
116 pelagic and the demersal domains.

117  
118 Changes in the structure and dynamics of marine food webs depend on a variety of factors,  
119 such as physical and chemical regimes, and the indirect and direct impacts of human activity  
120 and changes in biodiversity. Our current concepts of how pelagic marine systems function  
121 are based largely on modelling the responses of particular populations to physical and  
122 chemical forcing. These studies have been very successful in demonstrating the first-order  
123 role of physical and chemical processes. However, knowledge of the biological controls  
124 within marine ecosystems through density-dependent feedbacks across trophic levels are  
125 essential for understanding the longer-term persistence of systems, and especially their  
126 ability to switch between different, but ecologically coherent, regimes. The impact of  
127 changes in biodiversity on food-web structure and function is also a key factor in determining  
128 the impact of global change on marine ecosystems.

129  
130 Large-scale ocean research projects of the past decades have largely divided marine food  
131 webs into lower and higher trophic levels. JGOFS focused on phytoplankton, bacteria, and  
132 their relation to biogeochemical cycles and GLOBEC has focused on the forcing of the  
133 physical environment on zooplankton and fish. The major projects have not studied food  
134 webs as an entire ecosystem, from microorganisms to fish. To enable studies across all  
135 trophic levels, OCEANS will work collaboratively with GLOBEC to achieve a more complete  
136 understanding of the entire food web.

137  
138 We have a limited knowledge of the interaction of biogeochemical cycles and marine food  
139 webs. The JGOFS project has increased our knowledge of the relationships between the  
140 lower trophic levels and the carbon, nitrogen and silica cycles. Our knowledge of the impact  
141 of changing macro/micro nutrient availability and stoichiometry on phytoplankton, and the  
142 subsequent impact on higher trophic levels, remains very limited. In considering the effect of  
143 food webs on biogeochemical cycles, three classifications of food webs are useful: vertical  
144 exporters, upper ocean regenerators, and allochthonous importers. Diatom-dominated food  
145 webs, globally important to the biological pump, serve as examples of strong exporters. The  
146 effect of these food webs is to remove from the surface layer essential elements limiting  
147 growth (such as carbon, nitrogen, silicon, phosphorus, and iron), and delivering element-  
148 laden biogenic packages (fecal pellets and marine snow particles) to the meso- and  
149 bathypelagic or benthos for eventual remineralisation and storage. Removal of these  
150 elements from the surface ocean can feed back to the Earth System, as is the case with  
151 removal of atmospheric CO<sub>2</sub> to the deep ocean. Remineralisation and accumulation in the  
152 deep ocean creates the strong vertical gradients of the biophilic elements, thus satisfying

153 some of the conditions necessary for bloom development following winter overturn events.  
154 Regenerative food webs are characteristic of the nutrient-depleted surface waters found in  
155 subtropical gyres. These food webs display very high retention efficiencies for the limiting  
156 elements, thus favouring minute organisms with high turnover rates and low sinking  
157 velocities. Export to depth is minimized in these situations so as to maximize the productivity  
158 of these highly recycled, but limited, food webs. Food webs characterized as allochthonous  
159 importers are best symbolized by systems dominated by diazotrophs. These food webs  
160 have characteristics strongly overlapping the regenerator communities, but the introduction  
161 of new nitrogen via N<sub>2</sub> fixation allows export to take place, often with unusual stoichiometry.  
162 The impact on the mesopelagic is accumulation of nitrate in excess of phosphate expected  
163 from Redfield stoichiometry. Return of this water with non-Redfield stoichiometry to the  
164 surface may impact subsequent food-web character and development. The controls and  
165 feedbacks for any of these classes of food webs are poorly understood. The transition from  
166 one form to another, with subsequent impact on higher trophic levels, requires analysis.  
167 Understanding and modelling the complex system of biogeochemical and ecosystem  
168 feedbacks is an important integrating activity across disciplines, which address the  
169 interaction of the ocean with other components of the Earth System. Developing, validating,  
170 and testing the predictions of such models is impossible without a solid understanding of the  
171 interactions and the feedbacks between the components of the system being modelled, in  
172 this case the Earth System. OCEANS will investigate the regional manifestations of global  
173 change on biogeochemical cycles and ecosystems and the resulting feedbacks to the Earth  
174 System.

175

## 176 **C - OCEANS Domains**

177

178 The OCEANS project will build on previous and ongoing open-ocean euphotic zone studies.  
179 We must take advantage of existing and advancing capabilities (such as time-series studies)  
180 in the euphotic zone. In addition, a number of domains within the ocean have been identified  
181 as important in the context of global change and are poorly understood. These include the  
182 continental margins, the mesopelagic layer and high-latitude oceans. The OCEANS project  
183 will devote special attention to these domains to gain a sufficient understanding of the ocean  
184 system as a whole, to make possible accurate predictions of global change.

185

186 **Continental margins** are regions of high productivity that are significantly impacted by  
187 human activities. Input of nutrients, sediments and pollutants are high, and a large  
188 proportion of the global fish stock production and capture occurs in these regions. The  
189 continental margins are also a critical boundary for understanding ocean processes and  
190 provide the boundary conditions for modelling of open-ocean processes. The OCEANS  
191 project has adopted a functional definition of continental margins as the region between the  
192 land and the open ocean that is dominated by processes resulting from land - ocean  
193 boundary interactions. The exact dimensions of the margin depend on the issue of interest  
194 but attention is focussed on the unique aspects attributable to the boundary system and by  
195 definition generally consists of the continental shelf, slope and rise and will include marginal  
196 seas.

197

198 Recent global change research in the continental margins has focused on the budgets and  
199 cycling of carbon, nitrogen, and phosphorus (e.g., by LOICZ and the LOICZ/JGOFS  
200 Continental Margins Task Team), demonstrating that these regions can be responsible for  
201 significant drawdown of atmospheric CO<sub>2</sub> and cross-shelf export of carbon (Fasham et al.,  
202 2001). However, there has been less consideration of the exchange of nutrients and marine  
203 organisms across the continental margin-open ocean interface. Continental margins are  
204 characterised by a close coupling between the water column and the sediment, with surface  
205 water mixing down to the shallow sediment surface, thus strongly influencing nutrient cycling.  
206 Recent evidence indicates that margin sediments, especially in anoxic or suboxic conditions,  
207 are important sources of iron to phytoplankton in the overlying waters. Thus, the sediment-

208 water interface is critical to ocean biogeochemical cycles and their coupling. Investigating  
209 the remineralisation of nutrients within this boundary layer is essential for understanding their  
210 fate and transport throughout the ocean. OCEANS will seek to establish collaborative  
211 research with LOICZ, which has interests in nutrient and freshwater inputs to continental  
212 margins and biogeochemical cycles in this region.

213

214 **The mesopelagic layer** (defined here as the layer between 500 m, i.e., the bottom of the  
215 euphotic zone, and 1000 m; (Fasham et al., 2001)) has been identified as the most important  
216 ocean region for decomposition of organic matter and the recycling of nutrients (Fasham et  
217 al., 2001). Processes occurring in the mesopelagic layer control the remineralisation of  
218 organic matter produced in the overlying euphotic zone, yielding micro/macro nutrients  
219 available for phytoplankton production. Organic material that escapes remineralisation falls  
220 to the seafloor, where it is decomposed, consumed, or buried. However, many of the  
221 biogeochemical processes occurring in the mesopelagic layer are poorly understood.  
222 Mesopelagic ecosystems are structured vertically and horizontally by the changing  
223 biochemistry of particles and dissolved organic matter, and by the diurnal movements and  
224 migrations of organisms seeking to optimise feeding and reduce predation. The mesopelagic  
225 layer also links the euphotic zone and continental margins to the deep ocean. Knowledge of  
226 the structure and functioning of mesopelagic ecosystems is needed to provide an  
227 understanding of the processes responsible for exchanges among the euphotic zone, the  
228 benthos, and the ocean margins. It is also needed to enable prediction of responses of  
229 these exchanges to such diverse perturbations as climate change, iron fertilization, CO<sub>2</sub>  
230 injection, and increased exploitation of mesopelagic fish stocks. Understanding the  
231 biological and chemical processes in the mesopelagic zone will broaden our understanding  
232 of tightly coupled biogeochemical cycles in the ocean and how they will change in the future.

233 **High-latitude oceans** are regions of deep and intermediate water mass formation and  
234 ventilation. They are potentially regions of high productivity, and the globally significant high  
235 nutrient, low chlorophyll (HNLC) regimes. The deep and intermediate waters formed at high  
236 to mid-latitudes, are important reservoirs for anthropogenic CO<sub>2</sub> and serve as unique, but  
237 poorly understood, habitats for marine organisms in the mesopelagic zone. Cycles of sea-ice  
238 formation and retreat affect ocean ventilation, midwater storage of shelf-processed  
239 substances, and the cycle of ocean productivity in ice-edge ecosystems. Our understanding  
240 of the climate sensitivity of sea-ice coverage and intermediate and deep water mass  
241 circulation is therefore a key issue both for marine resources and future atmospheric CO<sub>2</sub>  
242 projections. Changes in stratification in high-latitude oceans will have impacts on regional  
243 food webs, with resonance through biogeochemical cycles. The largest HNLC region in the  
244 global ocean is located in the high-latitude Southern Ocean. The response of this system to  
245 global change may have a particularly strong feedback to the Earth System. An ensemble of  
246 recent observations and climate scenarios show a large change in high latitude oceans,  
247 affecting sea-ice thickness, mixed-layer dynamics, circulation and river plumes. Accurate  
248 representation of these systems within ocean biogeochemical and ecosystem models  
249 represents a major potential focus for future IGBP/WCRP collaboration.

250

## 251 **D - Intersection of OCEANS Domains with the Domains of Other Projects**

252

253 The OCEANS project will build on the approaches taken and the knowledge gained in  
254 previous projects. OCEANS will seek to make links with other projects to eliminate the  
255 important gaps in research activity of the past decades. In particular, OCEANS will foster  
256 collaborative research with GLOBEC to enable studies of food webs at all trophic levels;  
257 LOICZ in studies on the continental margins; SOLAS in terms of the impact of atmospheric  
258 inputs into the ocean and in the cycling of carbon in the ocean; CLIVAR, in terms of the  
259 impact of climate variability and change on marine biogeochemical cycles, ecosystems and  
260 their interactions; DIVERSITAS in relation to the how changes in biodiversity may impact

261 marine biogeochemical cycles and ecosystems; and GAIM in the development of models that  
 262 incorporate the feedback of the ocean to the Earth System.

263

## 264 **E - Approaches**

265

266 The OCEANS project must take new and innovative approaches to conducting marine  
 267 research. Past studies have focused on bulk biological processes rather than on the roles of  
 268 key species or functional groups. Our understanding of the distribution and functioning of  
 269 microbial communities, their dynamics, and their role in cycling materials in the ocean remain  
 270 at a rudimentary level. Yet, this knowledge is key to predicting ecosystem and  
 271 biogeochemical responses to global change. We need to develop models that address the  
 272 key species and specific functions of groups. We are now poised to apply novel techniques  
 273 (including enzymological and molecular methods that are targeted directly at the genome of  
 274 plankton at the level of individual) that allow direct quantification of specific functional groups  
 275 of organisms. These new approaches need to be extended to all trophic levels, from  
 276 microorganisms to top predators.

277

278 OCEANS will employ sustained in situ observations at current time-series sites, and  
 279 additional sites in key locations and through remote sensing. These will be complemented  
 280 by targeted process studies located near the time-series sites to better understand particular  
 281 processes. Integration and collaboration with complementary global change projects will  
 282 also be an important approach of the OCEANS project. OCEANS process studies will be  
 283 complemented by laboratory and mesocosm studies where appropriate. Extrapolation to the  
 284 global scale will require integration of the data from the CLIVAR repeat hydrography program  
 285 and other basin-wide, global surveys, employment of innovative observing and modelling  
 286 techniques, and interpretation of palaeoceanographic records. This nested approach will link  
 287 regional understanding to the global scale, thus providing the framework on which to build a  
 288 predictive capability the ocean system and its sub-systems.

289

## 290 **References**

291

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300

301 **The following Themes, and Issues within each Theme, are based on**  
 302 **the discussions and working group reports from the OCEANS Open**  
 303 **Science Conference in Paris 2003.**

304

### 304 **Theme 1 Interactions between marine biogeochemical cycles and ecosystems**

305

306 **Issue 1 Sources and sinks in biogeochemical cycles, and macro/micro nutrient**

307

308 **stoichiometry**

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310 **Issue 2 Role of macro/micro nutrient availability, assimilation and cycling in**

311

312 **controlling food web structure and function**

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314 **Issue 3 Relationships between biodiversity, structure, function and stability of**

315

316 **marine ecosystems**

317

**Issue 4 Role of species composition, ecological functional groups and organism**

**physiology in regulating biogeochemical cycles**

**Theme 2 Sensitivity of ecosystems, biogeochemical cycles and their interaction, to global**

**change**

**Issue 1 The impact of climate-induced changes in circulation, ventilation, and**

**stratification on biogeochemical cycles and ecosystems**

318	<b>Issue 2</b>	<b>Response of biogeochemical cycles, ecosystems, and their interactions, to increasing anthropogenic CO<sub>2</sub> and changing pH</b>
319		
320	<b>Issue 3</b>	<b>Response of biogeochemical cycles, ecosystems, and their interactions, to changes in the fluxes of macro/micro nutrients into the marine environment from land and air</b>
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322		
323		
324	<b>Theme 3</b>	<b>Feedbacks from biogeochemical cycles, ecosystems and their interactions to the Earth System</b>
325		
326	<b>Issue 1</b>	<b>Regional manifestations of global change on biogeochemical cycles and ecosystems, and the resulting feedbacks to the Earth System</b>
327		
328	<b>Issue 2</b>	<b>Oceanic regulation of atmospheric CO<sub>2</sub> concentration</b>
329	<b>Issue 3</b>	<b>Human impacts.</b>
330		