Introduction

The Biology Directorate at the National Science Foundation (NSF) has requested that organismal biologists develop a vision and articulate the grand research challenges that will drive the future of organismal biology and the large-scale community-wide efforts that would be needed to address those challenges. Over the past decade, organismal animal biologists have been slow to develop community-wide initiatives relative to other bioscience communities (e.g., molecular biologists, ecologists, evolutionary biologists, and plant biologists). In response to NSF’s request, the Society for Integrative and Comparative Biology (SICB) organized an effort to begin to articulate grand visions of the research questions that will form the foundation of future research in organismal animal biology (hereafter referred to as “organismal biology” for brevity). White papers, now known as contributions in the “Grand Challenges in Organismal Biology” (GCOB) series, have been published in *Integrative and Comparative Biology* over the past 2 years (Denny and Helmuth 2009; Denver et al. 2009; Satterlie et al. 2009; Schwenk et al. 2009; Mykles et al. 2010; Sih et al. 2010). These papers define a number of large-scale forward-thinking research efforts that cross the broad array of disciplines encapsulated by SICB and move organismal biology in new directions: (1) genotype–phenotype relationships, (2) integrating living and physical systems, (3) utilizing functional diversity, (4) organism-environment linkages, (5) evolutionary stability versus change, (6) how nonmodel organisms work, (7) garnering public support for organismal biology, (8) transforming organismal biology into 21st century science, (9) fostering inter-disciplinary and cross-disciplinary research to yield emergent principles about organisms, (10) community research efforts in addressing GCOB, and (11) the predictive power of organismal biology in the context of ecological and evolutionary change.

Implementing GCOBs

At the 2010 SICB annual meeting a workshop was held to initiate a dialogue across organismal...
Grand Challenges

The 2011 SICB GCOB workshop opened with a review of how previous efforts had unfolded. Other scientific communities have moved forward in addressing their own grand-challenge research objectives. In many cases, major research programs have resulted from coordinated efforts that involve building community interest, articulating that interest in a series of workshops and white papers, and consolidation of focus by the community to address specific scientific goals and identify (and obtain) required resources to reach those goals. For example, the systematics community initiated the “A Tree of Life (AToL)” program with the initial goal to identify evolutionary relationships among as many organisms as possible, especially at higher levels of organization, and in doing so address fundamental and important problems in ecology, agriculture, human health and society, and development of bioinformatic resources. The current focus among systematic biologists is a mission to assess and map as much of the Earth’s biodiversity as possible, thereby informing conservation efforts to preserve that biodiversity. The molecular biology community involved in plant sciences worked together beginning in the 1990s to launch an initiative to sequence the genomes of Arabidopsis (the primary model species for plant biology) and all of the major crop plants. While not every plant biologist...
participated, there was overwhelming support from the community in this initiative. In response, NSF launched a series of requests for proposal initiatives beginning in 1998 and including the Plant Genome Research Program, the National Plant Genome Initiative, Genome-Enabled Plant Research, Transferring Research from Model Systems, Tools and Resources for Plant Genome Research, and for fiscal year 2010, Comparative Plant Genome Sequencing. In 2000, the Arabidopsis research community proposed the “Arabidopsis 2010” project involving the determination of the function of every gene in the Arabidopsis genome by 2010. The plant community is now working on their next large vision, the 2020 project, as articulated in white papers (Raikhel, 2008). More recently, the plant biology community has launched the “iPlant collaborative,” a cybernetwork designed to help plant biologists develop interdisciplinary integrative research to address grand challenges in plant biology (http://www.iplantcollaborative.org). Software engineers at iPlant work to develop cyberinfrastructure including “Discovery Environments” to help biologists work on grand challenges. iPlant cyber-resources are allocated by a community-representative iPlant board of directors. Members of the ecology and environmental biology community have launched a series of initiatives aimed at solving large-scale grand challenges. In the early 1990s, the Sustainable Biosphere Initiative was launched by the Ecological Society of America (ESA) and resulted in a series of workshops and white papers that presented a 10-year outlook for ecological sciences. Centers and institutes including the National Center for Ecological Analysis and Synthesis (NCEAS), the National Evolutionary Synthesis Center (NESCent), and the National Institute for Mathematical and Biological Synthesis (NIMBios) have all shaped the way in which ecologists frame and address grand-challenge-scale questions. In recent years, the ecology and evolutionary biology community has published a new set of white papers to define the future of these centers. Presently there is a new competition for the next generation of a national environmental synthesis center that will stimulate research, education, and outreach at the interface of the biological, geological, and social sciences.

Organismal biologists are now in the early stages in developing community-wide initiatives such as those undertaken by the systematics community, plant biologists, and ecological and evolutionary biology communities. We have articulated ideas about grand challenges in organismal biology through SICB workshops and synthetic white papers (Denny and Helmuth 2009; Denver et al. 2009; Satterlie et al. 2009; Schwenk et al. 2009; Evans et al. 2010; Mykles et al. 2010; Robinson et al. 2010; Sih et al. 2010). A group of organismal animal biologists with primary affiliation in the American Physiological Society (APS) held a workshop in 2007 to discuss developing a National Center Network for Physiological Research, Integration, Synthesis, and Modeling (PRISM). The stated goals of PRISM (Carey 2007) were broad and forward-looking, but PRISM’s initial efforts were directed toward development of a center for research on the physiology of large mammals so as to preserve and maintain present expertise, not to develop a dynamic future for organismal biology. PRISM’s initial efforts have not gained traction, but discussion of PRISM at the April, 2011, APS may substantially shift the present goals of PRISM. We hope to see increased discussion among organismal biologists allied with SICB and APS so that we can work together on scientist-based, not scientific-society-based approaches to developing the resources necessary to address GCOBs.

**How to start addressing GCOBs?**

To encourage discussion of how a research community could meet GCOBs, a strawman framework was presented for how to progress from a GCOB idea to garnering the research support needed to address the GCOB (Fig. 1). In this plan, SICB Executive Officers would initiate the process by formation of a grand challenge steering committee (GCSC), which would work to identify one focal interdisciplinary GCOB question. The process of moving from that question to a forward-reaching 5–10 year research agenda then involves three design/discussion loops. Loop 1 is a process that involves a small group of selected field-leading scientists, loop 2 involves a broader group of scientists and students, and loop 3 involves a smaller group of scientists working to engage the community of organismal biologists at large and the public, including funding agencies, in the GCOB research agenda. In loop 1 (Fig. 1), the GCSC would identify relevant fields (e.g., biology, physics, mathematics) pertinent to the GCOB question and recruit leadership participants from each of those fields. Those participants would work together to refine
the GCOB focal question, produce a white paper on novel interdisciplinary approaches to addressing the refined GCOB question, and hold a workshop with additional participants. At the workshop (Fig. 1, loop 2), participants would interact in small subgroups organized to encourage novel interdisciplinary and emergent ideas about how to address the refined GCOB question, identify required resources, and generate a research plan. Subgroups would then be shuffled to generate a new set of interactions among participants, and the process repeated until the GCOB question and approach to addressing the question had been further refined (Fig. 1, loop 3). This workshop would result in a white paper explaining both the process and the outcome. This paper could be used to identify public support for the GCOB question, including networking with representatives from funding agencies and/or foundations. Another white paper would then be issued to communicate how the research community would coordinate their efforts in addressing the GCOB question, and this white paper, along with the others, could then be used as motivation for funding agencies to launch initiatives to support the sort of work outlined in these workshops. While abstract, members of the audience did find the plan to resonate with their expectation of a process that will ultimately address GCOB questions.

As an exemplar of how a community could meet GCOBs, current efforts in ecomechanics, the interface between the fields of ecology and biomechanics, were presented. Researchers in ecology and biomechanics have recently become aware of the potential utility of collaborative interaction, but the scope and direction of these interactions has not been defined. To craft a definition, a workshop (funded by the Partnership for Interdisciplinary Studies of the Coastal Ocean [PISCO]) was held in September 2009 at the Friday Harbor Laboratories. The outcome of this workshop was a “manifesto” detailing the potential highlights and roadblocks to fully developing the field of ecomechanics. Segments of this manifesto have been published as review articles, and there is the possibility that the entire document (and its ongoing revisions) will be made available online. A second workshop (funded by the Society for Experimental Biology) was held in Cambridge, England, in March of 2011. The output of this workshop will be a special dedicated edition of the Journal of Experimental Biology. The next step for ecomechanics will be to gather feedback, from both biomechanics and ecologists, on the vision spelled out in products of these workshops. The manner in which feedback will be obtained has yet to be determined, but could potentially take advantage of the capabilities of web-based “social” networks. We anticipate that feedback will allow

![Diagram](https://example.com/diagram.png)
fine-tuning of the vision for eco-
mechanics, from which research
agendas and the necessary funding
for such a research focus can be
established.

Participants’ discussion

Groups of workshop participants
were then tasked with discussing
the following two questions:

(1) How should a broad, cohesive
and long-term vision for or-
ganismal biology research be
developed?

(2) How can investment in this
long-term vision be sustained
and stimulated by organismal
biologists across all career
stages?

To facilitate small and productive
discussion groups, participants
were asked to distribute them-
selves among round tables. In all,
there were five discussion groups
with 8–10 people in each group.
Student scribes recorded the con-
tent of discussion. Discussion was
observed by SICB executive com-
mittee members as well as the di-
gerator and program officers from
the NSF Division of Integrative
Organismal Systems. Following
discussion, each discussion group
was called on to articulate their
main thoughts on the two discus-
sion questions.

Developing a long-term
vision

Ideas that emerged from the dis-
cussion of Question 1 involved
developing a SICB committee
(e.g., akin to the student and
postdoctoral affairs committee
via the SICB secretariat) that
would provide a leadership role
in developing GCOB activities.
Activities proposed included
workshops involving scientists at
a range of career stages, broaden-
ing interactions with other disci-
plines in animal biology as well as
in fields beyond biology, and de-
fining/refining a common vision
of the future of organismal biol-
ogy. The plant biology community
has effectively organized their
*Arabidopsis* 2010 and *Arabidopsis*
2020 (Raikhel 2008) projects
around a 10-year research activity
plan, and so integrative biologists
may be well served by adopting a
similar long-range vision to their
activities.

Workshops should address
broad questions (e.g., how do or-
ganisms respond to a changing
environment) that have the po-
tential to engage organismal
biologists from across SICB direc-
torates (as well as other societies
such as APS, Society for Devel-
opmental Biology, Animal
Behavior Society). The format of
workshops should encourage
 cross-fertilization among faculty,
postdoctoral fellows, and graduate
students in brain-storming ideas.
At these workshops, participants
should feel free to express ideas
without fear of intimidation or
reproach should their ideas be
deemed outrageous. The work-
shops should be summarized as
white papers intended to commu-
nicate broadly to interested mem-
bers of the research community,
and could serve as starting docu-
ments for cyberspace dialogues
on the subject through online forums
and wikis. In addition to dia-
logues, this cyberinfrastructure
could also be developed with ap-
lications to encourage sharing of
data and meta-analyses and the
development of networks to coor-
dinate research.

Broadening interaction with
other disciplines was viewed as a
component essential for address-
ing many GCOB research areas.
Overcoming communication bar-
rriers will allow better cross-
understanding of our fields,
especially in terms of mutual un-
derstanding of the research
challenges and specific questions.
Interdisciplinary approaches aid
in merging intellectual approaches
and material resources needed to
address large challenging ques-
tions. Sharing facilities and equip-
ment may improve cross-
fertilization of ideas by bringing
disparate groups together.
Interdisciplinary collaborations
require improving effectiveness in
communicating research topics
and rationale for why a given re-
search area is important.

There was considerable discus-
sion of what position SICB ought
to take regarding the focused
study of model versus nonmodel
organisms. The plant biology
community was successful in
their ultimate goals of crop-plant
research by starting with the
*Arabidopsis* genome sequencing
project as an initial foray into se-
quencing a plant genome. Is it
possible for SICB scientists to
come together in the way that
plant biologists have in the de-
velopment of models that will allow
us to address GCOBs from the
vantage of integrative and com-
parative biology? Doing so will
allow greater vertical integration
among levels of biological com-
plexity, and enhance our under-
standing, for example, of how
relationships between genes and
organisms vary in the context of
environmental change.

Sustaining a long-term
vision by organismal
biologists across all
career stages

Ideas that emerged from discus-
sion of Question 2 principally
centered on developing ways to
integrate research and educational
activities in a focused interdisci-
plinary setting. An exemplar for
how we have successfully done
this is the Antarctic biology
course sponsored by the NSF
and Polar Programs. This international course attracts biologists from across a wide array of disciplines and has also attracted participants from other scientific disciplines (e.g., engineering), all of whom have an interest in understanding life in the cold (and high and dry). The Antarctic course successfully merges across training stages (from graduate students to senior faculty) and provides an ideal environment for establishment of novel interdisciplinary collaborations. The focal point of this course away from a particular biological problem (e.g., developmental biology) to a broader question (e.g., life in the cold) is a key to the engagement of participants and aids in addressing the challenge that scientists from disparate disciplines have difficulty communicating with each other when immersed in their own field. This course helps biologists understand engineers and vice versa because both groups are put in an environment (literally, Antarctica) where they must think more broadly about what they are doing and why they are doing it.

Such opportunities for training may presently be unique to Antarctica, but they could be developed elsewhere and for addressing different grand-challenge questions. Summer courses at biological field stations (e.g., The Marine Biological Laboratory, Woods Hole Oceanographic Institute, Friday Harbor Laboratories, Hopkins Marine Station) have traditionally been wonderful immersion learning environments where students engage in subjects that cannot be effectively taught during a normal academic term. New summer field courses focusing on GCOB questions and that bring expertise from a wide array of approaches, such as the Antarctic biology course exemplar, could be very successful. Course instructors, like those in the Antarctic biology course, would bring their own research expertise to bear and also have the needed perspective to help bridge the disparate fields represented. Potentially, the development of national and/or regional centers for GCOB research could occur at these field stations and part of the center’s mission could be the summer GCOB courses. Such national and regional centers have been quite successful in the European systems where research is focused on a particular set of questions and/or areas (e.g., the Alfred Wegener Institute in Germany is focused on polar marine biology). These centers not only could provide both a place for intellectual exchange and data mining, but also could provide appropriate research facilities for engaging in actual work as required to address the GCOB. The Crary laboratory at McMurdo base in Antarctica provides discussion rooms and wet laboratories for the Antarctic Biology course; that blend is an integral aspect of the development of new collaborative efforts. The centers should provide shared tools and resources and help engage the community in science through effective communication and outreach.

To overcome the challenge of educating future generations of scientists such that they can work seamlessly among different scientific disciplines, both within biology and between biology and other fields, we need to develop some novel educational approaches that involve all career stages, especially undergraduate, graduate, and postdoctoral students. Educational efforts in training students to be integrative, to be interdisciplinary, and to have a broad perspective must start early. Novel undergraduate majors and perhaps new types of undergraduate degrees could be a great way to start. A suggestion was made to establish a new integrative organismal biology graduate student and/or postdoctoral funding opportunity specifically in topics related to addressing grand challenges in organismal biology through interdisciplinary approaches. Participants would be expected to engage in collaborative research between at least two laboratories representing different scientific fields. For example, to understand organism-environment linkages, one of the grand challenges posed by Schwenk et al. (2009), participants could work among laboratories that specialize in biology, geosciences, engineering, mathematics, and/or computer sciences relevant to a specific research question related to the grand challenge. Those laboratories need not be located at the same university, but must have research areas that in combination provide a new and effective way of addressing the GCOB. Graduate fellowships would involve rotations among each of the participant laboratories. Postdoctoral fellowships would also include Research Experiences for Undergraduates (REU) funding so that the postdoctoral scholar would gain experience in mentoring students, and undergraduate students would gain perspective on interdisciplinary approaches during the travel amongst participant laboratories.

Cyberinfrastructure will likely play an important role in the successful maintenance of GCOB efforts, especially in facilitating interdisciplinary communication. SICB members and other integrative organismal biologists could launch a site modeled after iPlant in which datasets could be standardized and used in
integrative meta-analyses, and through which researchers from disparate fields and physical locations could work together to integrate their approaches toward addressing GCOB questions. In addition to iPlant, effective grand-challenges cyberinfrastructure has been developed by research communities in engineering (http://www.engineeringchallenges.org/) and global health (http://www.grandchallenges.org/), for example. The engineering grand-challenges site has interactive polling and discussion forums, as well as dynamic content. Webinars could be organized to engage participants in GCOB discussions, and online forums for further discussion organized to enable frequent open communication among organismal biologists specifically centered on GCOB issues.

To keep a channel for discussion open, we have established a new website, (http://www.grandchallengesinbio.org/). At this site, we have established a forum to continue discussion on Questions 1 and 2 from our workshop, as well as other questions involving which of the GCOB questions we ought to be addressing first. Our future directions may well flow from a continued discussion about what process we ought to be following.

Finally, when moving forward in a coordinated group effort in seeking public support to transform the ways in which we approach our science, we must be mindful of GCOB questions of social relevance, best approaches in public communication, and strategies for garnering public support. Training in clear communication with policy makers, the media, and the general public is needed for the majority of our lead scientists, and getting that training should be a priority.

Conclusions

We urge the SICB Executive Committee to take interim action and establish the infrastructure needed to proceed with the organization to develop and meet the Grand Challenges in Organismal Biology. As evidenced in this document, a number of useful suggestions about both the challenges and the strategies for meeting them have been presented. Now, leadership must emerge that will organize, prioritize, and activate the efforts. We cannot make progress by concentrating on the Grand Challenges only once a year at our meetings. We recommend that a Grand Challenges Steering Committee of members committed to the effort be appointed immediately with the mandate to determine SICB’s initial foci, establish an action plan, and designate the leaders of each focus group, with the expectation that each group will develop a research or communication activity and seek funding for it. These groups should then report substantive progress at next year’s annual meeting. Only by taking action and developing focus can we begin to determine our future.

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