

INTELLECTUAL MERIT This proposal seeks funding to establish an RCN entitled *TraitNet*, which will coordinate trait-based evolutionary and ecological research. Traits are biological properties of species that influence individual fitness and govern how species interact with their biotic and abiotic environment. Traits are used across a broad spectrum of disciplines, including niche theory, community assembly, metabolic ecological theory, phylogenetics, conservation, and ecological stoichiometry. While each discipline has developed its own operational definitions, protocols, and databases, there is little coordination across disciplines. TraitNet will advance syntheses and analyses by coordinating integration among disciplines. Its five primary goals are (1) identify core hypotheses in trait-based research, (2) identify critical data gaps, (3) coordinate the standardization of collection and curation of trait data, (4) assemble a database to address core hypotheses, and (5) facilitate the development of cross-disciplinary computational tools for merging, disseminating, and sharing trait data. This network, made up of 5 working groups, will use electronic collaboratories, workshops, training seminars, and electronic and journal publication to address specific cross-disciplinary hypotheses, but will be structured more broadly by the goal of prototyping a universal trait database entitled *TraitBank*.

BROADER IMPACTS In the face of global change, species traits take on additional importance as tools for predicting the ecological and evolutionary response of species, communities and ecosystems to changing weather patterns, exotic species, and land use change. Additionally, there is naturally significant overlap among trait-based research disciplines so coordination will substantially minimize redundant collection efforts and maximize scientific productivity. TraitNet's website will be widely accessible to the scientific community and the public, while protecting the intellectual property rights of individual investigators. TraitNet will further diversity in science by maintaining a strong gender balance, including under-represented groups, and balancing participants among students, postdocs, and senior and junior researchers. Its core participants are listed in the table below.

NAME	AFFILIATION	NAME	AFFILIATION	NAME	AFFILIATION
D. Ackerly	UC Berkeley	E. Garnier	CNRS	B. Peet	U North Carolina
A. Baumert	U Pittsburgh	K. Jones	Zoo. Soc. Lon.	T. Pendergast	U Pittsburgh
E. Borer	OSU	M. Jones	NCEAS	P. Reich	U Minnesota
D. Bunker	Columbia U	C. Klausmeier	Michigan St. U	S. Romanello	LTERNet
J. Cavender-Bares	U Minnesota	J. Klironomos	U of Guelph	M. Schildhauer	NCEAS
J. Chave	U P. Sabatier	J. Knops	U Nebraska	E. Seabloom	Oregon State U
E. Cleland	NCEAS	R. Kobe	Michigan S. U	S. Spector	AMNH
S. Collins	UNM	S. Lavorel	AEL, France	K. Suding	UC Irvine
J. Cronin	U Pittsburgh	E. Litchman	Michigan St. U	D. Wall	Colorado State U
S. Diaz	U Nat. Córdoba	N. Martinez	PEaCE Lab	E. Weiher	UW Eau Claire
J. Dunne	PEaCE Lab	B. McGill	McGill U	R. Williams	Microsoft Research
B. Enquist	U Arizona	G. Midgley	SANBI, SA	K. Worm	U Nebraska
V. Eviner	IES	A. Moles	Victoria U	J. Wright	Duke U
B. Fagan	U Maryland	R. Montgomery	U Minnesota	S.J. Wright	STRI
J. Fargione	Perdue U	C. Mulder	NIPHA, NL		
L. Fraser	Thompson R U	S. Naeem	Columbia U		

OVERVIEW This proposal seeks funding to establish a five year Research Coordination Network (RCN), entitled TraitNet, dedicated to the advancement and integration of trait-based evolutionary and ecological research. Traits are variously defined, but essentially concern species' properties that affect individual fitness and govern species' impacts and responses to their environment. Trait-based research spans an enormous array of ecological and evolutionary disciplines. While each discipline has sought to define traits, apply trait data to test theory, establish protocols for the quantification of traits, and build multi-user databases, little coordination or interaction has occurred across disciplines. TraitNet addresses this extraordinary opportunity to facilitate integration and synthesis across this array of disciplines. TraitNet is structured by five goals (Figure 1):

1. *Identify key questions and Core Hypotheses* in trait-based research.
2. *Identify data gaps* that hinder the advancement of intra- and inter-disciplinary trait-based research.
3. *Coordinate the standardization* of collection and curation of trait data.
4. *Build a model database* to test explicit Core Hypotheses developed through TraitNet workshops.
5. *Facilitate the development of cross-disciplinary computational tools* for merging, disseminating, and sharing trait data. These activities will be structured around the design of a prototypical universal trait database, here referred to as *TraitBank*. *It is important to note, however, that TraitNet itself, as an RCN, will **not** undertake to develop TraitBank, but rather lay the groundwork for such a facility.*

These goals are explained in detail below.

BACKGROUND Species are characterized by homologous, analogous, and neutral traits¹ that collectively provide information about their ecology and evolution, providing a powerful means to predict both patterns in distribution and abundance (Grime 1979, Tilman 1982, Huston and Smith 1987, Brown 1995, Enquist 2003, Brown et al. 2004, Navas and Moreau-Richard 2005, McGill et al. 2006) as well as ecosystems processes (e.g., Gordon 1998, Eviner and Chapin III 2003, Kelso et al. 2003, Díaz et al. 2004, Eviner 2004).

¹ Homologous traits refer to traits shared by evolutionary descent, analogous to function, and neutral of no apparent influence on fitness. For example, feathers are homologous traits among bird species, where as wings are analogous traits among bats, birds, and insects.

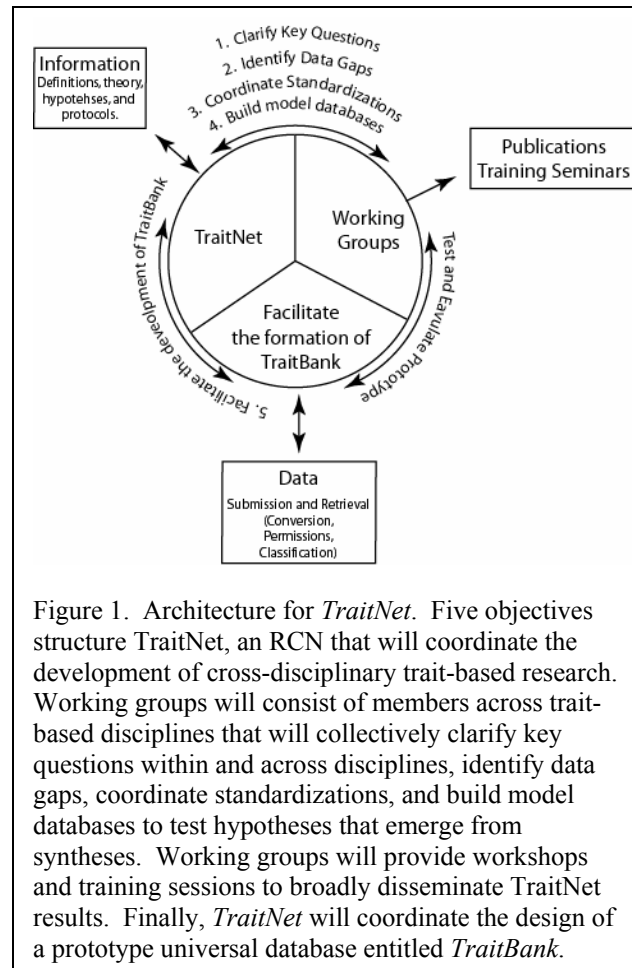
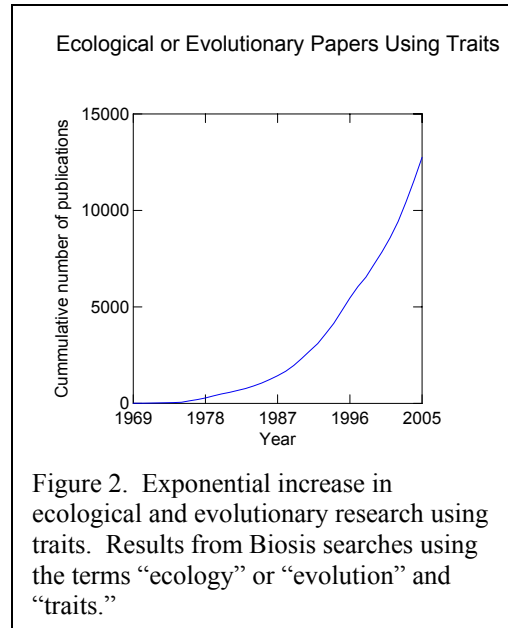


Figure 1. Architecture for *TraitNet*. Five objectives structure TraitNet, an RCN that will coordinate the development of cross-disciplinary trait-based research. Working groups will consist of members across trait-based disciplines that will collectively clarify key questions within and across disciplines, identify data gaps, coordinate standardizations, and build model databases to test hypotheses that emerge from syntheses. Working groups will provide workshops and training sessions to broadly disseminate TraitNet results. Finally, *TraitNet* will coordinate the design of a prototypal universal database entitled *TraitBank*.

Over the last 30 years, facilitated by dramatic advances in technology and ecoinformatics, trait-based ecological and evolutionary research has undergone an extraordinary expansion (Fig. 2). However, as the development of comprehensive vegetation databases (e.g., VegBank, Center for Tropical Forest Studies, and SALVIAS) and phylogenetic databases (e.g., Flora of North America, Tree of Life project) has proceeded rapidly, trait databases have remained specialized to a particular region, taxa, or set of traits.



A diverse array of both fundamental and applied disciplines in evolutionary and ecological research depend on trait data (Table 1). For example, the evolutionary ecology of species’ niches involves fundamental tradeoffs in seed size (Moles et al. 2005), leaf economic traits (Ackerly 2004, Wright et al. 2004), and allometric constraints (West et al. 1997). Using traits to predict the risk of species invasions (Veltman et al. 1996, Kolar and Lodge 2002, Lloret et al. 2005, Ruesink 2005), risk of species extinction (Gittleman and Purvis 1998, Foufopoulos and Ives 1999, Purvis et al. 2000), or crop responses to climate change (Lynch and St.Clair 2004) are examples of applied trait-based research. Mechanistic and predictive ecology similarly can rely heavily on trait data. For example, Solan et al. (2004) used traits to estimate changes in estuarine sediment turnover in the face of biodiversity loss and Bunker et al. (2005) forecasted changes in forest carbon sequestration under different management practices. Table 1 summarizes these and other examples of basic and applied research that are dependent on species trait data..

Table 1. A broad sampling of trait-based research where trait is broadly defined. Note that we leave off considering precisely what is or is not a trait. This is just the sort of question that TraitNet will be able to address, and TraitNet will incorporate trait concepts and protocols via peer review. Note also that broad areas such as trait-based taxonomy, trait-based phylogenetics, functional ecology, and morphometrics are not included for simplicity.

SUBJECT AREA	DESCRIPTION	EXAMPLE TRAITS	REFERENCES
Bio- and phyto-remediation	Using species to remediate pollution	heavy metal resistance, specific root length, root surface area, root volume and average root diameter	(von Canstein et al. 2002, Pulford and Watson 2003, Merkl et al. 2005)
Biodiversity and Ecosystem Functioning	Mechanisms by which changes in biodiversity change ecosystem functioning	soft and hard versions of response or effect traits	(Lavorel and Garnier 2002, Solan et al. 2004, Bunker et al. 2005, Thompson et al. 2005)
Comparative method	Using phylogenies and traits to understand evolutionary adaptation	traits such as leaf mass per area, seed mass, genome size.	(Ackerly 2004, Moles et al. 2005)
Community ecology	How trait filtering governs community composition and structure, including assembly rules, competition,	Body size, height, leaf traits, trophic position, light requirements, clonality	(Gaudet and Keddy 1988, Weiher and Keddy 1995a, Weiher and Keddy 1995b, 1999, Ackerly et al. 2002,

	facilitation and limiting similarity		Suding et al. 2003, Cavender-Bares et al. 2004, Suding et al. 2005, Grime 2006, McGill et al. 2006)
Conservation Biology	Estimate threat levels for species or likelihood of extinction	gestation period, range size, number of offspring, trophic position	(Gittleman and Purvis 1998, Foufopoulos and Ives 1999, Purvis et al. 2000)
Ecosystem ecology	Trait specific influences of organisms on ecosystem processes and biogeochemistry	woody caudices, multi-branched rhizomes, N-fixing symbiotic associations, C3 or C4 pathway	(Gordon 1998, Eviner and Chapin III 2003, Kelso et al. 2003, Diaz et al. 2004, Eviner 2004)
Gradient Analysis	Mechanisms and patterns of biodiversity along ecological gradients	R*, dispersal mode, reproductive structures, elements of leaf design	(Tilman and Wedin 1991, Thuiller et al. 2004)
Endemism	Determining what traits are associated with endemism	stature, dispersal, pollen/ovule ratios, number of flowers	(Lavergne et al. 2003, Lavergne et al. 2004)
Fire Ecology	Predicting fires based on plant traits	Resprouting capability, seed bank	(Saha and Howe 2003, Pausas et al. 2004)
Food Webs	Structure and dynamics of communities governed by trophic interactions	dietary or energy-transfer linkages and trophic position, body size, morphological traits	(Layman et al. 2005)
Functional Diversity	Identification and quantification of functional diversity	all traits	(Petchey and Gaston 2002, Mason et al. 2003, Botta-Dukat 2005, Mason et al. 2005, Mouillot et al. 2005)
Guild analysis	Grouping species by environmental resource exploitation irrespective of taxonomy	C3, C4, annuals and biennial forbs, ephemeral spring forbs, spring forbs, summer/fall forbs, legumes, and woody shrubs	(Simberloff and Dayan 1991, Kindscher and Wells 1995, Blondel 2003)
Heritability	Quantifying the heritability of species traits	Various traits	(Iyengar et al. 2002, Caruso et al. 2005, Garant et al. 2005)
Macroecology	Patterns of species adaptations at geographic scales	Body size, photosynthetic pathway, dispersal syndrome	(Brandle et al. 2002, Burns 2004, Morin and Chuine 2006)
Metabolic Theory of Ecology	Metabolism as a basis for linking individual organisms to population, community, and ecosystem ecology.	body size, physiological traits, and correlates such as growth, range	(Brown 1995, West et al. 1997, Enquist 2003, Brown et al. 2004)
Natural selection	How species evolve in response to selective pressure	Body size, fledging weight, dispersal syndrome, palatability, host specificity	(Boughman 2001, Etterson and Shaw 2001, Merila et al. 2001, Nosil et al. 2002, Beatty et al. 2004, Hoskin et al. 2005)
Paleobiology	Using leaf physiognomy to estimate past climate	Leaf size, leaf morphology	(Royer et al. 2005, Royer and Wilf 2006)
Plant Ecological Strategies	How plant species “secure carbon profit during vegetative growth and ensure gene transmission into the	leaf-span-per-area and leaf-lifespan are important traits;	(Hodgson et al. 1999, Westoby et al. 2002)

	future”		
Population Ecology	Predicting properties of dynamics (e.g., probability of extinction)	body size, age at first reproduction, or number of offspring	(Fagan et al. 2001, McGill et al. 2006)
Species Invasions	Predicting invasiveness of species based on traits	body size, endemism, reproductive rate	(Veltman et al. 1996, Lloret et al. 2004, Hamilton et al. 2005, Lloret et al. 2005, Ruesink 2005)
Succession	Temporal change in communities predicted by traits	Respiration rate, seed number, growth rate, maximum life span, induced dormancy, R*, stress tolerance	(Grime 1979, Tilman 1982, Huston and Smith 1987, Navas and Moreau-Richard 2005)
Unified Neutral Theory of Biodiversity and Biogeography	Trait neutral core patterns in distribution and abundance, forms contrasting hypotheses to trait-based patterns	dispersal, growth rates	(Hubbell 2001, Nee and Stone 2003, He 2005, Hubbell 2005, Ostling 2005, Wootton 2005)

TRAITNET: ENABLING INTERDISCIPLINARY RESEARCH – Clark et al. (2001) suggest that “Technical construction of [ecological] forecasts requires initiatives to develop new or augment existing data networks and to support experimental research.” Given the wide range of both fundamental and applied trait-based research (Table 1), the dramatic rate of growth in trait-based research (Figure 2), and the rapidly emerging technologies associated with trait-based research (discussed below), here we suggest that trait-based research, like ecological forecasting, requires a coordinated initiative to develop new network that will facilitate trait-based research. TraitNet will serve the research community by supporting new, cross-disciplinary trait-based research.

Hypotheses derived from cross-disciplinary research are often characterized by a scope that requires multiple traits collected uniformly from a diversity of species across widely dispersed localities. The TraitNet working groups will explore and identify such hypotheses, determine data needs and gaps, develop and test model datasets for addressing these hypotheses, and coordinate the establishment of trait databases, guidelines and training for their use, and enable a variety of multidisciplinary research activities. As Table 1 illustrates, the potential number of cross-disciplinary approaches is very large.

Core Hypotheses. At the first TraitNet workshop, working groups will explore and select two to three Core Hypotheses to serve as working models for TraitNet. Here we provide three of the many possible examples.

- *Dimensionality of life-history trade-offs.* While an endless number of traits can be measured on individuals and species, many traits are highly correlated with one another, and it has been suggested that relatively few trade-off axes can explain the majority of variation in plant form and function (Grime 1979, Coley et al. 1985, Charnov 1997, Reich et al. 1999, Hubbell 2001, Westoby et al. 2002). How are species life histories constrained by these fundamental trade-offs, how many axes of differentiation exist, and how does the extent of these trade-offs vary across environmental gradients and among biomes? These key questions require data on multiple traits, collected from multiple species, from multiple sites, and standardized where different protocols were used.
- *Mechanisms of exotic species invasions.* The success of invasive species has been often attributed to an escape from natural enemies, whereby one would predict successful invaders

to have ‘better’ traits than the native species they displace, such as greater height, lower R^* , or lower construction costs (Nagel and Griffin 2001, Bunker 2004, Gaudet and Keddy 1998, Miller and Werner 1987, Seabloom et al. 2003). Alternatively, the success of some invaders has been attributed to novel traits, such as nitrogen fixation (Vitousek and Walker 1989) or allelopathic effects (Bais et al. 2003), that allow them dominate new habitats. While both mechanisms certainly play a strong role, the relative importance of each in driving species invasions is not clear. An effective test would require species trait data on plant invader species, on the native species they may displace, on palatability to native herbivores, and data on traits of potential natural enemies such as body size, diet, and growth rates.

- *Predicting species, community and ecosystem responses to global change.* Predicting the response of species to climate change, pollution, and land use change is a key challenge to ecologists. These predictions could be developed by correlating species traits with either observed responses to global drivers or across natural environmental gradients. In either case trait data from a wide variety of species, across multiple trophic levels, from a variety of habitats would be required. Similarly, predicting the effects of these global drivers on ecosystem function will require additional trait data that mechanistically link species with their per capita effects on ecosystem functioning. (Etterson and Shaw 2001, Solan et al. 2004, Bunker et al. 2005)

Scope of TraitNet. TraitNet aims to bring together species trait data from a variety of taxa across different trophic levels and from a variety of habitats and locations to address specific interdisciplinary hypotheses (see examples above). Our initial coverage will be greatest among terrestrial plants because several focused plant trait networks are well developed and will serve as useful starting points (Table 2). The interdisciplinary hypotheses chosen for study by the network of participants will likely require traits of herbivores, predators, detritivores, and other trophic groups as well. Additionally, TraitNet will not limit itself to terrestrial systems and may select aquatic ecosystems or transition habitats such as wetlands. To that end, we have assembled a group of core participants that is weighted towards terrestrial plant ecologists due to current trends in the literature and also includes researchers who specialize in insect, mammalian, microbial, aquatic and disease ecology. These core participants will actively recruit additional investigators within their respective areas of expertise. TraitNet participation is expected to grow substantially once established and we identify additional researchers who focus on other habitats, taxonomic groups, and trophic groups. Table three describes the diversity of taxonomic focus and expertise of core and general TraitNet participants.

Table 2. Examples of databases that include trait data. **Current collaborators** in bold.

Database name	Description
BiolFlor	Focuses on the German flora and includes >60 traits and >3600 plant species.
BioPop	Database of plant traits of the Mid-European flora including 60 traits and >4700 species.
Center for Tropical Forest Science Trait Database	A newly initiated effort to collect functional trait data for 6,200 tree species found in 18 large forest dynamics plots located in 14 tropical countries.
Ecological flora of the British Isles	Database of plant traits of the flora of the British Isles including >130 traits and >1700 plant species.
Ecological flora of California	A database of ecological characteristics, including life history, phenology, morphology and other traits, for the California flora. Under development by David Ackerly.

FishBase	Worldwide fish species database with more than 29,000 species.
Glopnnet	Global compilation of leaf economic traits from >2500 plant species. Initiated by Peter Reich, Ian Wright and Mark Westoby.
Hawaii Plant Trait Database	A database of systematic, biogeographic, functional, physiological and ecological data for Hawai'i's native and alien flora. Initiated by Rebecca Montgomery, Lawren Sack, Becky Ostertag, Susan Cordell, and Jon Price
LEDA Traitbase	Focuses on the Northwest European flora and plant traits that describe three key features of plant dynamics: persistence, regeneration and dispersability. Not yet available online.
NatureServe Explorer	Conservation data on more than 50,000 plants, animals, and ecological communities of the United States and Canada.
NatureServe InfoNatura	Conservation information on the more than 5,500 birds, mammals, and amphibians of Latin America and the Caribbean.
Seed Information Database, Kew Botanic Garden	Database of seed characteristics, including storage behaviour, weight, dispersal, germination, oil content, protein content, morphology, for several thousand plant species, with plans to include >24,000 species.
USDA Plants	The PLANTS Database provides standardized information about the vascular plants, mosses, liverworts, hornworts, and lichens of the U.S. and its territories. It includes names, distributional data, characteristics, images, and crop information.

THE CHALLENGES OF DATA INTEGRATION

Much of what TraitNet aims to accomplish will rely on integrating data from disparate sources. Integrating disparate data is a complex process with many challenges. These challenges are not trivial. Here we outline the main issues and describe our approach to addressing them. In order to meet these challenges, we have included several informatics experts in our group of core participants, representing several organizations including the Science Environment for Ecological Knowledge project (SEEK), the Pacific Ecoinformatics and Computational Ecology Lab, and the Microsoft European Science Initiative. To address our Core Hypotheses, we will build a model database that also will serve as a training ground for building a fully accessible and open source trait data archive termed TraitBase. While the development of a universal trait database such as TraitBase is beyond the scope of this RCN, we will lay the groundwork for such a venture.

Intellectual property rights – Intellectual property rights are a critical issue for any research network and even more so when data is aggregated from multiple sources. Trait-based research progresses best when data sharing is maximal, but currently the sharing of raw data is not common except within groups. Workshops, collaboratories, training sessions, and the TraitNet website will provide a forum for discussion of the many issues surrounding intellectual property rights and how they would affect database tools, resources, and the design and implementation of TraitBank in the future.

To that end, we propose that data owners will retain full rights and full control over their data. TraitNet will facilitate collaborations between participants that would otherwise be less likely to occur. Our model database will be fully searchable whereby one could search for all available traits for a particular species, or all species with a particular trait, or for a set of traits among a set of species. If participants so choose, we can set up the search system to return only whether the

data exist, and who owns the data. It would then be up to the participant to contact the data owner and propose a collaboration.

Taxonomic standardization – Definitions of biological taxa change with *taxonomic revisions* over time. For instance, a single species may be split by one revision into several species, and then lumped back into a single species in subsequent revisions. A trait value measured on the lumped species cannot be assigned to any one of the split species, and a trait value measured on one of the split species cannot be assumed to represent the entirety of the lumped species. In addition, species are often cited with only the name authority, but not the underlying taxon concept reference. For these reasons, taxonomic names by themselves cannot be considered a unique index for TraitNet datasets. This obstacle applies to all data that are specific to individual species, such as GenBank, VegBank, etc.

Fortunately, efforts are underway to address this complex issue. The SEEK Taxon project has created an internationally accepted standard for taxonomic data, the Taxonomic Concept Schema (TCS), and work is underway to implement the Taxonomic Object Service (TOS), a repository and web service allowing for translation between taxonomic concept authorities. TraitNet will collaborate with SEEK Taxon to ensure that our database schema will function with the TOS when it is fully functional and populated with taxon concepts.

To ensure that TraitNet data will be compatible with TOS, TraitNet will require that participants include name authorities *and* taxon concept references, as well as subspecies when appropriate, in their data submissions. Only in this way we can specify, for each record, the taxonomic concept upon which the measurement was taken. For instance, a full taxon concept reference might be: “*Aus beus* Sarg. 1893 sec. Smith 1989,” where Smith 1989 is a link to the reference in which the concept is described or defined (Figure 3).

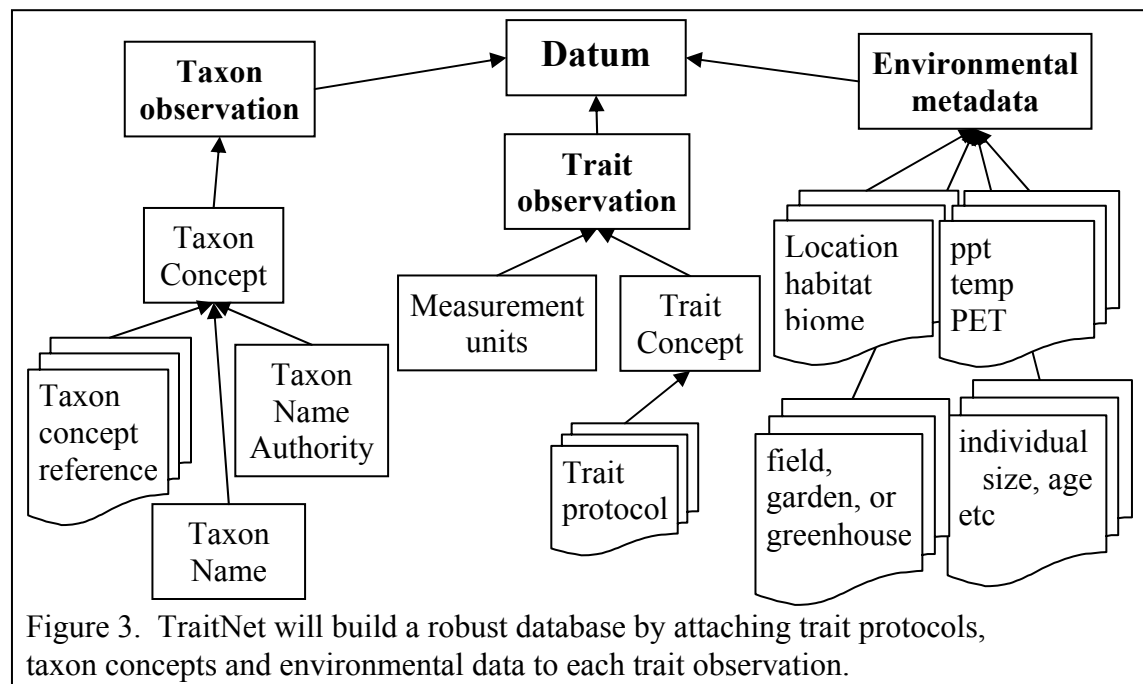


Figure 3. TraitNet will build a robust database by attaching trait protocols, taxon concepts and environmental data to each trait observation.

We will also utilize TaxonScrubber, a utility developed as part of the SALVIAS project in Brian Enquist’s lab, to automate the standardization of taxonomic names. TaxonScrubber splits concatenated information into separate fields and conforms entries to the taxonomic concepts

and spellings of the Missouri Botanical Garden's TROPICOS database, with current development including the International Plant Names Index. TaxonScrubber can utilize other taxonomic concepts as needed. TraitNet will work directly with SALVIAS to adapt TaxonScrubber to our needs.

Changes in trait collection protocols introduce challenges that are similar to those introduced by taxonomic revisions. A trait concept may remain fixed, but the protocol used to quantify the trait may change as new protocols are introduced. A trait database must be able to incorporate revised trait collection protocols as they are developed to ensure that data produced through all protocols for a given trait concept are quantitatively comparable. For example, wood density is the trait concept of mass per unit volume. However the protocol to collect wood density varies. Wood mass may be measured on oven-dry wood samples or on air-dried samples with 12-15% moisture content. Both metrics quantify wood density, but data from air-dried samples must be corrected to account for the moisture content. TraitNet will define trait concepts and associated trait collection protocols. Each trait protocol for a given trait concept must be quantitatively comparable (Figure 3).

TraitNet will build on current ecoinformatic efforts to address these issues. Ecological Metadata Language (EML) has been developed by NCEAS' Knowledge Network for Biocomplexity project and is widely considered the standard for documenting metadata for ecological datasets. The SEEK project has extended and formalized critical aspects of EML in the Observation Ontology (OBOE), a formal model of scientific observations that includes trait measurements. Thus TraitNet will use and extend EML to specify the Taxon Concepts, Trait Concepts, and associated environmental data outlined in Figure 3. Eventually, these trait concepts will be included in SEEK's formal ontologies such as OBOE.

Because species trait data are used for such diverse research ends, the data must be collected and archived with sufficient metadata to ensure wide applicability to potentially *unforeseen research questions*. For instance, an investigator may collect wood density data with the intention of calculating above-ground biomass at a given site. However, future investigators may ask how wood density varies within species at a given site, within species across environmental gradients, among species, among size classes, or even throughout the year. To ensure that a given trait observation contains maximum scientific value, the collector will want to document explicitly the conditions under which it is collected, including latitude and longitude, habitat, individual age or body size, time and date of collection, etc, etc. Many trait observations, such as wood density, require substantial effort and/or expense to collect. Only minimal additional effort is required to collect substantial metadata, metadata that will ensure that a trait observation has lasting scientific value (Figure 3).

Finally, an ideal network environment would also: 1) allow for automated integration of trait data contributions; and 2) include a web-enabled search engine that would allow user-friendly access to the general public, including students, educators, and policy makers. While these goals are beyond the scope of the current proposal, we will develop our protocols, thesauri and metadata requirements with these goals in mind. Our collaborations with SEEK and input from the ecoinformatics experts among our core participants will ensure that our efforts are fully compatible with emerging ecoinformatic tools.

COORDINATION AND MANAGEMENT PLAN

The goals of TraitNet will be carried out via a series of three major workshops, an online collaboratory, an online database, and a series of educational training seminars (Table 3). TraitNet will be organized around a number of working groups. All core participants will serve on one Theory and one Trait working group, as well as one of the three solitary working groups (Technology, Education, and Steering). Working groups will meet during each of the three workshops in years 1, 3 and 5, and collaborate via bi-monthly online collaboratories.

Working Groups

Theory working group Theory working groups will develop concise summaries of major theory, their hypotheses, and required traits. These groups will then identify the data required to accomplish research goals, and identify data gaps. We expect that the membership and foci of theory groups will change as research agenda develop. All core participants will be involved in one or more Theory group.

Trait working group Trait working groups will develop trait concepts and collection protocols. Each trait group will focus on classes of traits, such as leaf economic, reproductive, allocational, defense, etc. Fortunately, much of the work to identify key traits and develop appropriate concepts and protocols has already been done, and we will draw upon these efforts (e.g., Cornelissen et al. 2003., Weiher et al 1999, Westoby 1998, Westoby et al. 2002, Leda TraitBase protocols). Trait groups will work directly with international collaborators including the Leda TraitBase, Glopnet and BiolFlor, among others. Trait groups will also develop controlled vocabularies and thesauri to facilitate integration of related traits (e.g., LMA and SLA) and traits collected under various protocols. The thesauri will define explicit relationships between various collection protocols to allow heterogeneous data to be incorporated into the database. These efforts will focus initially on the data archives and collection efforts of network participants. In this way, we can begin by integrating our own data. As additional researchers join TraitNet, additional protocols may be developed to facilitate the incorporation of additional data. We will utilize a system of peer-review throughout TraitNet to ensure that all trait concepts, protocols and data contributions meet community standards. All core participants will be involved in one or more Trait groups.

Cross-taxa working group The cross-taxa working group will focus on extending much of what has been developed for plant traits to other taxa. For several reasons, plant ecologists have tackled traits quite formally, while with other taxa traits have been utilized in a less formal manner. The cross-taxa group will work to identify successful trait protocol and concept strategies that may be particularly suitable for other taxa, ranging from bacteria and fungi to mammals. Initial cross-taxa working group members include: J. Cronin, D. Bunker, E. Garnier, B. Fagan, K. Jones, E. Lichtman, J. Klironomos, E. Lichtman, N. Martinez, C. Mulder.

Technology working group The Technology working group will be responsible for developing a strategy for implementing the database and curation protocols, and ensuring that TraitNet efforts will project forward to ecoinformatic initiatives being developed by seek. The actual implementation would be carried out by the Associate Director and the Computer Programmer. Initial technology working group members include: D. Bunker, J. Dunne, B. Enquist, B. Fagan, M. Jones, M. Schildhauer, R. Peet, D. Wall, E. Weiher, R. Williams.

Education working group The Education working group will be responsible for developing an educational program designed to introduce TraitNet and its associated tools to interested scientists at annual scientific meetings such as ESA, Evolution, etc. These seminars will train

investigators to document thoroughly their data collections via metadata tools such as Morpho and thus enable seamless participation in the network. These workshops and our website would be the primary means of recruiting new participants to TraitNet. Initial education working group members include: D. Bunker, S. Diaz, M. Jones, M. Schildhauer, S. Romanello, R. Williams.

Steering committee TraitNet will be governed by a steering committee composed of core participants from each working group, with a rotating membership. The steering committee will meet annually to define the overall goals for TraitNet, set budgeting priorities and to ensure accountability from the individual working groups. Initial steering committee members include: D. Bunker, S. Diaz, S. Naeem, M. Schildhauer, R. Peet.

External review TraitNet will undergo an external review by independent experts in years 2 and 4. The Principle Network Coordinator will identify 4 senior scientists, not affiliated with TraitNet, to serve as external reviewers. The external reviewers will have representative expertise in trait-based research, systematics, vegetation plot archiving, and ecoinformatics.

PERSONNEL

Principle Network Coordinator The Principle Network Coordinator will be responsible for the conceptual development, management and oversight of TraitNet. The Principle Coordinator will: (1) serve as lead author/editor for products; (2) secure resources (space, internet access, equipment); (3) coordinate activities for securing additional funds for expansion or refinement; (4) commission external reviews; (5) attend NSF RCN workshops.

Associate Network Coordinator The Associate Coordinator (salaried Co-PI) will coordinate and oversee the implementation of directives from the RCN, and manage day-to-day Network activities. The Associate Network Coordinator will: (1) lead database and website development; (2) coordinate with programmer; (3) coordinate workshop logistics; (4) assist with external review; (5) attend NSF RCN workshops; (6) coordinate with national and international institutional partners.

TraitNet Programmer This computer programmer (or programmers, part-time, salaried) will coordinate directly with the Associate Coordinator, and be responsible for database design. Before the first Workshop, the programmer will establish a database schema for the initial aggregation of participant data, and continue after the first workshop to integrate participant datasets. The programmer may be an NCEAS or SEEK programmer retained by TraitNet for a short period. If not, the programmer will undergo training at NCEAS to become familiarized with Ecological Metadata Language and associated ecoinformatic tools develop by SEEK and NCEAS.

Core Participants Develop the conceptual framework, develop trait concepts and protocols, design TraitNet web, provide data, peer-review trait concepts and protocols as well as data contributions, co-author products. Core participants will be the main workshop attendees.

General Participants Distributed international network of trait-based researchers, students, and educators who will participate in TraitNet. Participants will provide review, provide feedback, beta-test model databases, and contribute to all phases of TraitNet's activities. Attendance of workshops can be arranged if self funded. Attend training sessions at national meetings.

Note: The Principle and Associate Coordinators have substantial experience coordinating scientific research through the BioMERGE RCN (Naeem and Wright 2003, Solan et al. 2004,

Bunker et al. 2005, Wright et al. 2006, Cardinale et al. in review). In addition, the Associate Coordinator (Bunker) has substantial training in ecoinformatics through the SEEK project, and is the webmaster for the BioMERGE project.

TIMELINE

Year 1. *Clarify key questions, Identify data gaps, and begin data aggregation.*

Principle and Associate Coordinators: teleconference with Steering committee to incorporate NSF panel and reviewer recommendations and strategize and implement TraitNet; hire TraitNet Programmer; review core and general participant feedback, construct working groups, and organize and convene Workshop 1.

Associate Coordinator: builds electronic network and initiates discussion of trait definitions, disciplines, and opportunities for cross-disciplinary research among network participants.

Prior to workshop 1, Associate Coordinator and programmer will work together with participants to describe available datasets using Ecological Metadata Language so we can summarize available data at the first workshop.

Workshop 1 tasks:

Steering committee: Review and establish conceptual framework

Theory working groups: 1) Describe central theory, hypotheses, objectives, and challenges of trait-based research; 2) Identify opportunities for cross-disciplinary trait-based research; 3) Identify Core Hypotheses and associated research agendas, as well as data gaps; 4) Identify the critical environmental metadata (Figure 3) desirable for individual trait observations.

Trait working groups: 1) Define trait concepts and associated trait protocols (data dictionaries); 2) Where multiple protocols exist for a given trait concept, quantitatively define relationship between the trait values of various protocols (thesauri); 3) Coordinate with Technology working group to implement trait concepts and protocols into Ecological Metadata Language.

Cross-taxa working group: 1) Identify commonalities between and among traits for various taxa; 2) How extensible are plant trait methods to other taxa? 3) Identify and recruit additional participants within their field of expertise.

Technology working group: 1) Develop near-term database schema to accommodate trait concepts, taxon concepts and environmental metadata; 2) Develop trait concept and protocol guidelines to ensure that TraitNet data dictionaries and thesauri will be compatible with formal ontologies under development at SEEK; 3) Work with Trait groups to document metadata in EML; 4) Develop long-term database schema to facilitate the incorporation of additional traits and taxa.

Education working group: Coordinate with Technology and Trait working groups to develop user friendly tools and protocols for trait annotation.

Year 2. *Coordinate Standardization and Build Model Databases.*

Principle and Associate Coordinators: Teleconference with Steering committee to evaluate progress and structure calendar and targets for TraitNet in its second year; provide two year progress report to external review committee.

Associate Coordinator and programmer: develop model databases to address hypotheses derived from selected cross-disciplinary challenges in collaboration with technology working group and other ecoinformatic specialists; convene collaboratories to establish trait concepts and protocols, standardization of metrics, and beta-test model databases.

Participants begin to utilize model database to address Core Hypotheses.

Year 3. *Electronically publish trait concepts and protocols, test Core Hypotheses with aggregated traits data, identify tools and infrastructure required to expose TraitNet to the wider scientific community and the public via TraitBank.*

Principle and Associate Coordinators: teleconferences with Steering committee to evaluate feedback from external review committee, strategize for Workshop 2, and establish calendar and targets for year 3; coordinate Workshop 2 at NCEAS.

At workshop 2:

Theory working groups: Address Core Hypotheses with aggregated trait data, begin or continue analyses and manuscript preparation;

Trait working groups: 1) Review and finalize trait concepts, associated trait protocols; 2) Publish trait concepts and associate trait protocols on website; 3) develop additional trait concepts and protocols as additional participants join TraitNet.

Technology working group: 1) Identify tools and infrastructure required to bring the TraitNet approach to the wider scientific community and the general public.

Education working group: Develop Educational Training Seminars to be presented at ESA and Evolution annual meetings (*see* Educational Training Seminars, below).

After workshop 2, Associate Coordinator, in collaboration with the Technology working group, will establish a web-enabled search mechanism for the model database and invite network participants to test and evaluate.

Principle and Associate Coordinators and core participants publish framework and summaries of cross-disciplinary challenges electronically and in journals, and present findings at national meetings. Associate Coordinator and working groups clarify cross-disciplinary challenges.

Year 4. *Facilitate the Development of Interdisciplinary Trait Database Tools.* Steering committee teleconferences with Principle and Associate Coordinators to evaluate TraitNet findings, progress, problems, and develop calendar for fourth year. TraitNet will have had sufficient experience with interdisciplinary trait-based research, hypothesis testing, and have to hand database tools and model databases that can serve as the foundation for the larger enterprise of working towards a universal trait database. Collaboratories are used to consider the development of needed database tools and the framework for a potential universal trait database entitled *TraitBank* modeled after GenBank.

Principle and Associate Coordinators: prepare 4-year report for external review committee; present findings at national meetings and introduce concept of TraitBank; seek funding and collaborations to establish TraitBank in following year.

Associate Coordinator: coordinates draft universal trait handbook sections; organizes final training session. Representatives from the Education working group present seminars at ESA and Evolution annual scientific meetings.

Year 5. *A Universal Handbook and Database for Trait-Based Research.* With feedback from external review committee, Principle and Associate Coordinators establish Workshop 3 at Columbia University. Working groups consider feasibility, challenges, resource needs, technology needs, and the remaining challenges of TraitBank based on TraitNet's collected findings and experiences with model databases. The architecture for a TraitBank prototype is developed. The Associate Coordinator and programmer, in coordination with ecoinformatic specialists in the network, develop prototype as designed at Workshop 3 to use for proposed funding and implementation of TraitBank.

At Workshop 3,

1. review handbook sections
2. review proposed design for TraitBank
3. develop timeline and challenges for the implementation of TraitBank

Principle and Associate Coordinators organize symposium at national meeting to review TraitNet's findings.

Associate Coordinator; coordinates TraitNet participant finalization of handbook and plan for release prior to national meetings; organizes final training sessions. *Representatives from the Education working group* present seminars at ESA and Evolution annual scientific meetings.

EDUCATIONAL TRAINING SEMINARS Training seminars will be presented at ESA and Evolution annual scientific meetings in years 4 and 5. These seminars will introduce TraitNet and associated protocols, concepts and tools to investigators at all levels. Registration fees will be reduced or eliminated for young investigators to encourage participation. Seminars will cover various areas of trait-based research and TraitNet, including: 1) the scope of trait-based research; 2) ecoinformatics and the value added to trait observations by quality metadata; 3) the interpretation and implementation of TraitNet concepts and protocols. Seminars will be presented by the Associate Coordinator, core participant Samantha Romanello, an ecoinformatics education specialist at SEEK and LTERNet, and a trait-based research specialist among the core participants. training seminars, the website, and word or mouth will be the primary means for attracting additional participants to TraitNet.

COLLABORATORIES AND WEBSITE TraitNet will rely on web-based tools to ensure rapid and effective communication among participants. At a minimum we will implement a wiki web site, enabling participants to post rapidly ideas and materials to a central, easily accessible repository. We may also develop a more formal collaboratory by partnering with the Science of Collaboratories Project, based at Howard University and the University of Michigan.

COORDINATION WITH EXISTING GROUPS AND INTERNATIONAL PARTNERS Worldwide, many groups are currently working to aggregate species trait data. These groups are all doing great work, yet we feel there is an opportunity to accomplish far more by bringing these groups together. To that end, we should emphasize that we do not intend to duplicate work already accomplished nor to compete with these existing groups. By serving as an umbrella network we can leverage these ongoing efforts. Some of the more formal groups we are working with include Glopnet, the Leda TraitBase, BiolFlor, The Ecological Flora of California, and ScarabNet among many others.

In addition to collaboration with groups dedicated to the collection of traits, we will also partner with groups and institutions dedicated to compiling species and community level data. For instance, NatureServe has compiled extensive species accounts that include conservation status, range maps, and ecology and life history characteristics. Our efforts would expand on their 'ecology and life history characteristics' by providing highly quantitative and geographically registered characteristics. We would also be in a position to contribute to, and expand upon, the USDA Plants database and the Tree of Life project.

Our efforts will also compliment the many networks devoted to the aggregation of community level data, such as VegBank, SALVIAS, LTERNet, MorphBank, and the Center for Tropical Forest Science. By assembling the traits of species in the ecological communities cataloged by these partner networks, we will enable a more thorough understanding of community dynamics.

ENHANCING NETWORK PARTICIPATION AND DIVERSITY TraitNet is composed of more than 30 core participants from the ecological, evolutionary and informatics research communities (Table 3). Potential members were identified via a literature survey and recommendations from colleagues. TraitNet is geographically and ethnically diverse, has a balanced gender ratio and includes a mix of grad students, post-docs, and junior and senior scientists. The goal of TraitNet is to include any and all researchers that utilize species traits in their research. To that end we will nurture broad participation from the scientific community via Educational Training Seminars at annual scientific meetings such as ESA and Evolution, as well as through exposure via our website.

ANTICIPATED PRODUCTS

Scientific publications, including: (1) research findings from tests of Core Hypotheses targeted at *Science* or *Nature*; (2) the framework, targeted for *Ecology Letters*; (3) special features of examples of trait-based research targeted for *Ecology*, *Oikos*, or *Functional Ecology*; (4) review targeted for *TREE*; and (5) a symposium volume following the final workshop, targeted for a publisher that will be willing to release the volume in paperback at affordable prices.

Resources for trait-based research, including: (6) an electronic trait handbook containing trait concepts and protocols.

Bioinformatic tools, including: (7) a prototype for TraitBank in the fifth year that will serve as a model for a larger endeavor designed to meet the trait data needs of the larger scientific community and the public; and (8) associated informatic tools designed facilitate aggregation of trait data.

CONCLUDING REMARKS: INTELLECTUAL MERIT, BROADER IMPLICATIONS AND POST RCN VISION TraitNet is designed to meet the goals of the NSF RCN program by coordinating a wide array of scientific disciplines that are centered on a specific research theme but would benefit enormously from cross-disciplinary coordination. TraitNet will facilitate cross-disciplinary research among ecological and evolutionary fields centered on trait-based research by the activities described in this proposal. The broader implications of TraitNet are also substantial. TraitNet would not be limited to serving researchers. The products will serve a wide array of fundamental and applied scientists, students, and educators in ecology, evolution, and environmental biology. Additionally, TraitBank has the potential to be much more than a resource for natural scientists. While the emphasis will be on use by ecologists and evolutionary biologists addressing hypotheses generated from trait-based ecological theory, many other uses

are envisioned. A birder or botanizer wishing to obtain a list of bird species in the region they are visiting. A teacher on a field trip may wish to design an exercise based on species at a local site. A student writing a paper on certain taxa could find trait data for their work. Any individual, be they student, teacher, researcher, collaborative research team, agency scientists, conservation scientists, or NGO researchers, could access TraitBank over the web from a field site, classroom, laboratory, or office. Trait data in the public domain would be immediately accessible, from measurements to photos.

Table 3. Current TraitNet participants. **Core participants** in bold.

<u>Name</u>	<u>Affiliation</u>	<u>Name</u>	<u>Affiliation</u>
D. Ackerly	UC Berkeley	G. Midgley	South African National Biodiversity Institute
E. Ayres	Colorado State U	C. Mitchell	U North Carolina
A. Baumert	University of Pittsburgh	A. Moles	Victoria U of Wellington
E. Borer	Oregon State University	R. Montgomery	U Minnesota
D. Bunker	Columbia University	C. Mulder	NIPHA, Netherlands
J. Cavender-Bares	University of Minnesota	H. Muller-Landau	U Minnesota
J. Chave	U Paul Sabatier	S. Naeem	Columbia U
E. Cleland	NCEAS	B. Ostertag	U Hawaii-Hilo
S. Collins	U New Mexico	B. Peet	U North Carolina
S. Cordell	USDA Forest Service	T. Pendergast	University of Pittsburgh
H. Cornelissen	Vrije Universiteit	J. Price	USGS
J. Cronin	University of Pittsburgh	P. Reich	University of Minnesota
S. Diaz	U Nat. de Córdoba	S. Romanello	LTERNet
J. Dunne	Pacific Ecoinformatics and Computational Ecology Lab	L. Sack	U Hawaii-Manoa
B. Enquist	University of Arizona	M. Schildhauer	NCEAS
V. Eviner	IES	E. Seabloom	Oregon State U
B. Fagan	University of Maryland	B. Simmons	Colorado State U
J. Fargione	Perdue University	S. Spector	AMNH
L. Fraser	Thompson Rivers U	P. Stevens	NCEAS
E. Garnier	CNRS	K. Suding	UC Irvine
K. Jones	Zoological Soc. London	D. Wall	Colorado State U
M. Jones	NCEAS	M. Walters	Michigan State U
C. Klausmeier	Michigan State U	E. Weiher	UW Eau Claire
J. Klironomos	University of Guelph	K. Worm	University of Nebraska
J. Knops	University of Nebraska	J. Wright	Duke U
R. Kobe	Michigan State U	S.J. Wright	STRI
S. Lavorel	Alpine Ecology Lab	I. Wright	Macquarie U
E. Litchman	Michigan State U		
N. Martinez	Pacific Ecoinformatics and Computational Ecology Lab		
B. McGill	McGill University		