Using Biophysical Information in Policies for Agroecosystem Services in California*

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I. INTRODUCTION

Ecosystem services are the conditions and processes through which ecosystems sustain and fulfill human life, and they result from the interaction of organisms and their environment (Daily 1997). The four types of ecosystem services are: provisioning services such as food and fiber production; regulating services such as waste decomposition and water quality; longer-term supporting services such as soil formation and nutrient cycling; and cultural services such as aesthetic and spiritual fulfillment (Daily 1997, MEA 2005). The concept of ecosystem services allows the evaluation of multiple aspects of management decisions simultaneously. In California's agricultural landscapes, emphasis on agricultural provisioning services has often outweighed regulating and supporting services, but the current trend toward agricultural sustainability has begun to shift the priorities to the more holistic set of ecosystem services.

The broad concept of sustainability is characterized by a set of complementary goals: producing food, fiber, and forest products, protecting the resource base upon which humans depend, and promoting social well-being, which includes various factors associated with quality of life, including economic security. Complementarity implies that solutions are sought that meet each of these criteria. Evaluation of ecosystem services creates a mechanism to determine sustainability outcomes, usually by assessing the tradeoffs that arise under different management scenarios, and choosing the options that generate greater multifunctionality. Agricultural multifunctionality can be defined as the joint production of commodities (i.e., food and fiber) along with other ecosystem services (Jordan et al. 2007). Thorough analysis of costs and benefits of different management options requires a combination of biophysical (e.g., ecology, agronomy, soil science, hydrology, atmospheric science, and engineering) and socioeconomic (e.g., economics, anthropology, sociology, and law) disciplines, since multifunctional ecosystem services encompass a wide set of potential human needs and values. This interdisciplinary analysis is a core aspect of sustainability science (Kates and Parris 2003), which regards these costs and benefits as tradeoffs. In the agricultural policy realm in the USA, however, multifunctionality is less likely to be regarded as a product, but

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rather is apparently considered an inherent aspect of the marketable output itself, through implied provision of additional environmental or cultural services, such as wildlife habitat and/or through recreational opportunities.

Environmental problems are usually associated with a set of intricate and interrelated issues. For California, this presents considerable complexity, given the diversity of soils, ecosystems, and agricultural production systems. Taking the example of carbon (C) sequestration, using some generalized assumptions, modelling has shown that from 1980-2000, California's 3.6×10^6 ha of agricultural land sequestered 11.0 Tg C within soils and 3.5 Tg C in woody biomass, for a total of 14.5 Tg C (i.e., 14.5×10^{12} g) (Kroodsma and Field 2006). This corresponds to 0.7% of California's total fossil fuel emissions over the same time period. The challenge is to determine how best to increase C sequestration, without reducing yields and income across the wide range of California soils and crops (>300 crop commodities), which respond differently to practices such as conservation tillage and cover cropping (Jackson et al. 2004, Minoshima et al. 2007). Other issues introduce even more complexity than this example, e.g., improving water and air quality, avoiding salinization, and conserving and restoring biodiversity. Determining the tradeoffs involved in providing a range of ecosystem services for California's farmland is not trivial, since incorrect decisions can cause damage, financial loss, and create skepticism among policy makers in the future.

How can biophysical scientists contribute to a better understanding of the ecological processes in California's agroecosystems that generate multifunctionality, and convey these outcomes for use in policy decisions by land users and other stakeholders to increase ecosystem services? The aim of this chapter is to address this central question considering three components. First, some background on interdisciplinary science is presented, showing the need for partnerships with stakeholders, so that innovation is conveyed through setting up new types of research frameworks. Second, an attempt is made to identify factors that underlie the past perceived dichotomy between provisioning services vs. other ecosystem services in California agricultural landscapes. Third, the potential for positive interlinkages of agroecosystem services is considered in a California context, using examples that focus on complexity. The outcome of the paper is to show the need to invest in policy that supports the provision of multiple ecosystem services through adaptive management, i.e., 'the process by which land managers gain understanding of the complex issues for managing their land, recognizing that science alone cannot provide all the answers, and that it must be combined with local community-based or participatory approaches to solve problems' (FAO 2003).

II. INTERDISCIPLINARY AND PARTICIPATORY APPROACHES

Interdisciplinary research, combined with participatory approaches that engage various types of stakeholders, is now a well-recognized framework for linking science and policy in agricultural landscapes (Jackson et al. 2007, Tomich et al. 2007). Covering the scope of ecosystem services necessitates a range of disciplines within the biophysical sciences. While multidisciplinary approaches tend to coordinate disciplinary research, interdisciplinarity strives for greater integration and synthesis, which usually requires a start-to-finish, on-going effort. Partnerships and participatory approaches among researchers, farmers, and other stakeholders to integrate biophysical and socioeconomic research are instrumental in understanding ecosystem services and the tradeoffs of different management scenarios.

The landscape is an appropriate scale for understanding ecosystem services, because it encompasses many types of agricultural production units, along with water, air and biodiversity resources, and interactions with human populations. An agricultural landscape broadly includes resources and organisms in farm fields, fragments of natural ecosystems, canals and waterways, urban zones, and other land uses in regions dominated by agriculture. A landscape emphasis is embodied in recent decisions to operate conservation policies at the watershed scale, e.g., the Conservation Reserve Enhancement Program (CREP) and the Conservation Security Program (CSP) (Arha et al. 2007).

The landscape includes a set of hierarchical levels, each of which involves a set of unique management factors and ecological issues, and thus provides an overarching context for understanding a range of ecosystem services: food and fiber production, biodiversity-related services in both agricultural and non-agricultural ecosystems, water quality on-farm and in adjacent waterways, etc. In ecology, five main hierarchical units are recognized within landscapes; these form the basis for different questions and focal points when examining biophysical processes. For each level, scale pertains to the issue at hand, e.g., ecosystem processes can be measured in a cm^3 of soil, or across an entire farm. These levels define ecological processes, but also help to frame management options for solving different types of problems across agricultural landscapes:

Autecology (Individual level of ecology): The organism and its interaction with its environment, including ecophysiology, e.g., adaptation of cultivars or livestock breeds to specific environments

Population ecology: Populations within a species and the interactions within and between populations that influence survival and reproduction, e.g., dispersal behavior that affects pest outbreaks

Community ecology: Groups of organisms, their interactions, and their interaction with the environment, e.g., predatory, parasitic, and mutualistic interactions that affect beneficial and pest organisms

Ecosystem ecology: The composite of organisms, materials, and environment, and the flows of materials and energy in the system as a whole, e.g., cycling of nitrogen in fertilizer and soil organic matter to plants, through residue decomposition, and as atmospheric and groundwater losses

Landscape ecology: The reciprocal interactions between ecosystems, often at the interface between differing ecosystems, with emphasis on the flows of materials and how they are affected by social forces, e.g., water quality in riparian corridors and other waterways that results from water delivery and runoff from a multitude of farm fields, and as influenced by policies and legal agreements.

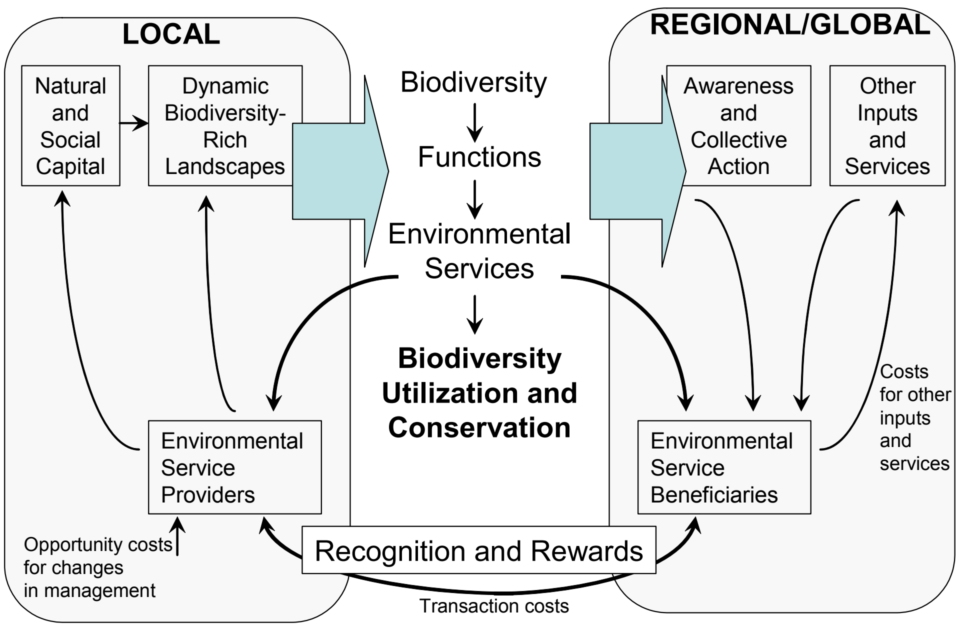
Although ecological functions underpin ecosystem services in agricultural landscapes, ecologists have been largely absent from this discussion until recently (Palmer et al. 2004). There has been an historical tendency for ecologists to focus on natural, wildland environments, because these systems were thought to be free from human disturbance. Ecology is one of many disciplines that can inform policy on ecosystem services within agricultural landscapes. Better integration is needed with other disciplines with a long history of research in agricultural landscapes, e.g., agronomy, hydrology, and soil science. These sciences and their literature are not always recognized by those in the ecological community who advocate management for ecosystem services (Goldman et al. 2007). Rather than act as design agents who specify practical solutions (Palmer et al. 2004), ecologists should serve as one component of an interdisciplinary framework, and work with stakeholders over the long-term towards adaptive management.

Interdisciplinary networks that include partnerships among researchers, the agricultural community, and other stakeholders in the agricultural landscape are an emerging concept. One example, envisioned by the global project on Alternatives to Slash and Burn Programme (ASB) for conserving biodiversity and its ecosystem services, involves feedback between local, regional, and global entities that generates a reward system for the local land users who provide the ecosystem services desired by society (van Noordwijk et al. 2004) (Figure 1). The reward system might be payments for ecosystem services, funding for projects to improve land stewardship, or other types of support that increase livelihood security, e.g., increased water deliveries. Without recognition and rewards, conservation methodologies are neither reliable nor feasible, especially for land managers who are facing low financial profits or uncertainty. One role of an interdisciplinary network is to provide the scientific evidence that ecosystem services are indeed achieved by the targeted management plans, and that natural and social capital increases as a result. Another role is to serve as a conduit for negotiations between parties. In the ASB Programme, the following issues have been recognized as necessary for successful negotiations for payments for ecosystem services in regions where agricultural intensification is negatively affecting the resource base in tropical forested areas (van Noordwijk et al. 2004, Jeanes et al. 2006):

1) VALUE (to 'sellers' and 'buyers') is clear
2) THREATS linked to land use activities are urgent
3) OPPORTUNITIES exist to overcome the THREATS linked to land use activities
4) Sufficient TRUST exists to get buyers, sellers & government to negotiate deals

In California, it may be useful to consider application of these concepts not only for actual projects that require financial investment to conserve or restore ecosystem services, but also to support the types of research that are most conducive to voluntary adoption of practices that increase environmental quality and social well-being. In this paper, the focus is on the first three issues, due to their dependence on biophysical information. The development of trust among negotiating parties has a greater foundation in social science, so is not emphasized here. Also, the provision of cultural services and environmental justice is not a central focus of this paper, since its value is largely assessed in terms of human well-being, which falls within the domain of social sciences.

Figure 1. Linkages between providers and beneficiaries of environmental services derived from dynamic biodiversity-rich landscapes, each supporting biodiversity utilization and conservation by different mechanisms. Adapted from van Noordwijk et al. (2004). Re-printed from Jackson et al. (2007) (no copyright permission obtained).



III. DICHOTOMY BETWEEN PROVISIONING SERVICES VS. OTHER ECOSYSTEM SERVICES IN CALIFORNIA AGRICULTURAL LANDSCAPES

Policy for managing agricultural lands for ecosystem services is not a new concept. Agricultural conservation policy in the USA since the 1930s has supported the technical and outreach infrastructure to improve environmental quality, particularly soil conservation. But the conceptual framework has been changing during the past 20 years, as pointed out by Cox (2007). For example, during the 1930s, when drought and dust storms created agricultural turmoil in the USA, policies to limit soil erosion and land degradation centered on their effects on provisioning services, i.e., on agriculture's traditional focus on increased production. More recently, the awareness has changed to a broader environmental agenda for agriculture, in which the environmental cost of agricultural erosion has become equally or more important than the on-site damage to agricultural production. Drinking water quality is a major issue. Another is nutrient and sediment deposition in aquatic habitats that causes excessive plant growth and microbial decomposition, and decreases oxygen to levels that are detrimental to fish and other animal populations, i.e., eutrophication. In other words, both regulating and supporting services are increasingly recognized as important for multiple human values in agricultural landscapes.

Cultural services are also part of achieving agricultural sustainability, given their influence on human well-being and quality of life, not only for rural populations but for urban dwellers. There is a growing 'local food' movement in which people from different sectors are supportive of farming systems and food systems that engage the local community. Agrotourism/nature tourism is another example by which cultural services are delivered through recreation and refreshing the human spirit. While these activities increase the emphasis on conserving and restoring biodiversity in agricultural landscapes, there are public health concerns that have created a backlash against the juxtaposition of agriculture with wildlife habitat, e.g., eliminating natural habitat around vegetable fields due to a strain of *E. coli* on spinach which killed three people in 2006, and matches the DNA of *E. coli* in cattle, wild pigs, and stream water of a nearby grassland (Bailey 2007). It is difficult to reconcile this immediate health crisis with the perception of the farmer as steward of the environment; both issues involve different aspects of human well-being.

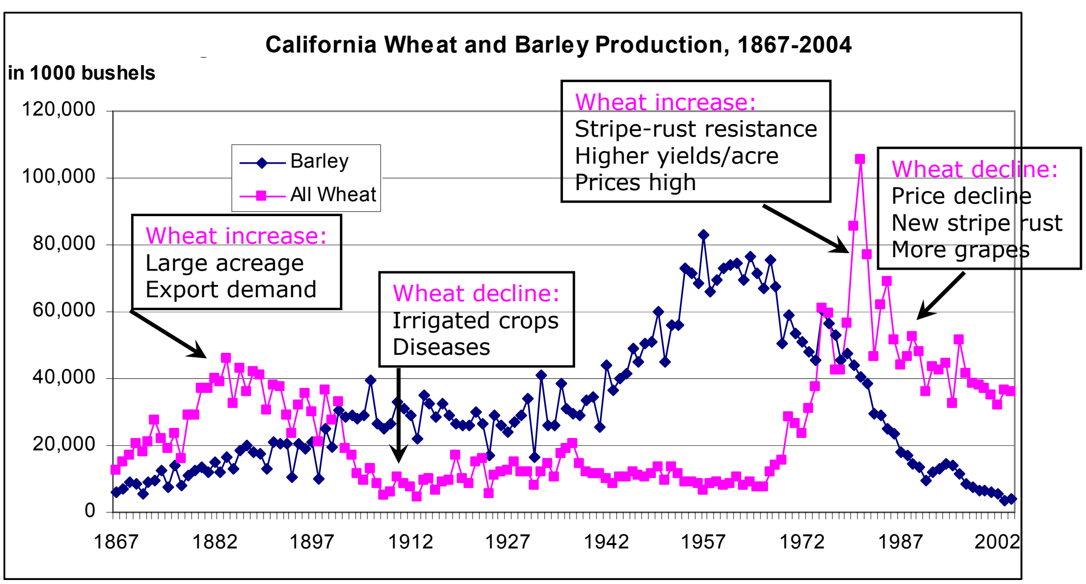
Provisioning services

Agricultural commodities have historically been the focus of most agricultural research in California, as elsewhere. California has a set of relationships between federal (USDA Agricultural Research Service), and state (University of California) organizations that have promoted programs for crop breeding, management, and agricultural engineering. This has led to tremendous increases in production and shifts in production throughout the state during the past century (Alston et al. 1994). California's agricultural abundance has depended on policies that have promoted the research capacity to continually select for crop genotypes with improved pest resistance, higher productivity, and desirable horticultural traits. This research capacity has contributed to California's leading position in USA agricultural production for several decades. Specialty crops are particularly important since the state produces about half of USA-grown fruits, nuts and vegetables, many of which are solely produced in California. Thus, provisioning services provided by California agricultural production, especially by specialty crops, can justifiably be mandated at the federal level, as recently shown by the new Farm Bill support for strengthening the competitiveness of the specialty crop industry through federal nutrition programs, and invasive pest and disease programs.

Improvement of provisioning services by California commodities is also facilitated by international research policy for conservation and use of genetic resources. For example, wheat production peaked in the early 1980s in California (Figure 2). This was due in large part to overcoming an outbreak of stripe rust, by changing to higher-yielding varieties that were resistant to stripe rust that were introduced from Mexico through the breeding programs of the Rockefeller Foundation in the 1960s, and later from International Maize and Wheat Improvement Center (CIMMYT)] [Anza, Yecora Rojo, and other cultivars] and University of California at Davis [Yolo cultivar] (C. Qualset and P. McGuire, pers. comm.). This activity was spurred on by the fact that wheat prices were high. Then wheat production declined due to lower prices, and to the increase in acreage of higher-value commodities, such as grapes. However, in August 2007, wheat prices are at all time high and new wheat plantings are underway. Although production of relatively low-value crops, such as wheat and barley, likely will remain volatile due to variability in prices and markets, competing crops and land resources, and disease and pest resistant varieties, California still has active public breeding programs for these crops.

In California, the individual initiative of public breeders has been the main avenue for identifying, acquiring, and using genetic resources for crop improvement. The majority of current collections in California were made before the establishment of the international Convention on Biological Diversity (CBD), which has made international access to genetic resources more complicated due to legal requirements involving sovereignty and intellectual property rights (CBD 2007). At the same time, there has been a huge reduction in the number of public breeders at the University of California. California also has the largest population of private crop breeders of any state. They are effective in developing and marketing varieties, but for many crops, they look to the public University of California at Davis (C. Qualset, pers. comm.). Sharing the advanced breeding lines was a deliberate goal of the University of California program, along with availability to statewide University of California Cooperative Extension trials. To sustain the level of advancement will require a public policy decision at the state level to restore crop breeding programs for current and new crops, and to facilitate the acquisition and maintenance of genetic resources upon which future provisioning services will be based.

Figure 2. California wheat and barley production, 1867-2004, as compiled from the National Agricultural Statistics Service and the University of California Agricultural Issues Center. Annotated information was provided by C. Qualset and P. McGuire of the University of California Genetic Resources Conservation Program.



Crops with higher water and nutrient efficiency would supply provisioning services with less impact on water supply and water quality, i.e., regulating services. Although crop improvement in California breeding programs has rarely focused on traits that increase water or nutrient use efficiency, there are situations in which this has unexpectedly occurred. Breeding of processing tomatoes has increased average yield per acre dramatically over the last 30 years. Yields of processing tomato in California were about 25 Mg/ha in the late 1940s (Gould 1983), and are now over 81 Mg/ha (Hanson and May 2006). Although yields have increased more than 50% since the 1970s, evapotranspiration rates (*i.e.*, water loss via evaporation and plant use) have kept constant at an average of 648 mm during the past 30 years (Hanson and May 2006). This remarkable finding reflects the inadvertent selection for water use efficiency that has occurred during several decades of tomato breeding in California. The traits responsible for these changes are not known at present. Changes might have occurred at the leaf level by increasing carbon assimilation per unit of leaf area, or by reduction of total leaf area. The determinate growth habit now typical of processing tomatoes has probably contributed to the gain in yields. In fact, water use and conservation is seldom a focus for research in tomato production, and only 1-3% of the papers on tomatoes in horticultural scientific journals address water-related issues (J. Seigies, pers. comm.). Due to the dependable supply of water from the federal and state water projects, water use efficiency may not have attracted the attention of major research initiatives for California crops.

Regulating and supporting services

Unlike for provisioning services that produce food and fiber that were described above, research on the landscape-level processes that affect regulating, supporting, and cultural services has been less directed and has not had the same level of coordinated, institutional support in California. As a result, there are still major gaps in the understanding of basic processes that underpin these services, and even when this has been achieved, implementation of management alternatives is often slow.

A relevant example of the lack of emphasis on regulating and supporting services is from the Salinas Valley, where production of lettuce, broccoli, and celery has dominated the landscape for many decades. The emphasis of USDA Agricultural Research Service and University of California agricultural research, usually associated with commodity boards, has been on disease and pest management, production increases, and post-harvest quality. For example, the California Lettuce Research Board (CLRB 2007) has expended its funds since 1980 in four categories: 1) plant breeding and virus research - $6,112,559; 2) insect and disease management research - $3,003,082; 3) cultural and weed management research - $749,158; and 4) post harvest and miscellaneous research - $418,350. Nitrogen and irrigation management has been a small portion of the total expenditures. These crops, however, have high nitrogen and water requirements, and the cost of these inputs is small in relation to the total cash value of the crop (UCCE 2002). Irrigation water and N fertilizer are often over-applied, and the fertilizer alternatives, such as cover crops, are much more difficult to manage (Jackson et al. 1994, Jackson et al. 2004). The Central Coast Water Board's (CCWB) monitoring program shows significant water quality problems in this region (Jones et al. 2006). Nitrate is present in some surface waters at levels far exceeding the drinking water standard. Groundwater basins underlying some of the agricultural areas show that nitrate concentrations are often higher than the drinking water standard, resulting in well closures and loss of water supplies (Basin Water Inc. 2005, Jones et al. 2006). Presence of routinely-used organophosphate pesticides (chlorpyrifos and diazinon) have been documented in adjacent surface waters, as well as persistent toxicity to aquatic organisms (Anderson et al. 2003).

Water quality in the Salinas Valley is a growing concern to public agencies (e.g., State Water Resources Control Board, the US Natural Resource Conservation Service) as well as local groups, such as the Salinas Valley Water Coalition. Because Salinas Valley surface waters flow to the Monterey Bay and negatively impact marine life, a Water Quality Protection Program (WQPP) was developed for the Monterey Bay National Marine Sanctuary, which is a partnership of 25 federal, state, and local agencies, and public and private groups, dedicated to protecting and enhancing water quality in the Sanctuary and its watersheds (MBNMS 2007). Such partnerships have begun to recognize and reduce the dichotomy that has occurred in managing for provisioning vs. regulating, supporting, and cultural services in California, and pave the way for development of more sustainable options.

IV. POTENTIAL FOR POSITIVE INTERLINKAGES OF AGROECOSYSTEM SERVICES

Managing for multifunctional agricultural landscapes is inherently complex. There are no simple solutions. There has been a tendency, however, to adopt a ‘keep it simple’ approach within the agricultural research community, especially for intensively-managed farming systems in the temperate zone. The research challenge is to find ways to describe and manage the complexity within agricultural landscapes, so that diverse sets of stakeholders express concerns over the threats to ecosystem services that they find important, that viable opportunities exist to solve problems, and that sufficient trust exists to negotiate solutions (van Noordwijk et al. 2004, Jeanes et al. 2006). Negotiation of solutions involves economic analysis (Stoorvogel et al. 2004), but also recognition of social bonds and norms among stakeholders that alter decision-making. When people are well-connected in groups and networks, and their combined knowledge is used in planning and implementation of conservation activities, sustained stewardship of natural resources is more likely to occur over the long-term (Pretty and Smith 2004). California examples include the California Alliance of Family Farmers (CAFF), the Biologically Integrated Farming Systems (BIFS) Project, and the Wild Farm Alliance.

The traditional education and extension models of the land grant university systems in the USA have not been conducive to the success of interdisciplinary research teams that involve the cooperation of academics with various types of stakeholders (Francis et al. 1995). First, these systems have been focused on single disciplines. Second, the tendency has been to foster the independence and achievements of individual scholars, due to the types of expected outcomes (e.g., published papers in the scientific literature) and rewards (e.g., merit and promotion success), which can be hindered and delayed by the intricacies of interdisciplinary science. Yet in California, there has clearly been a recent increase and interest in projects that take team approaches to solving problems that involve a complex set of tradeoffs for different types of ecosystem services. This may have occurred for the following reasons: 1) increasing awareness of the inadequacy of single-discipline research for problem-solving at the landscape level; 2) new types of analytical approaches (e.g., access to high resolution geographic information systems (GIS), multivariate statistics, and models) that make teamwork more feasible and interesting; 3) greater recognition of innovation by non-academic stakeholders in dealing with tradeoffs in complex situations; and 4) increasing institutional support for combining fundamental and outcome-oriented research approaches at the landscape level.

The following short examples highlight three projects that have involved University of California researchers, using different types of interdisciplinary, participatory approaches to deal with complex problems in agricultural landscapes. Each example represents a different scale. One is an analysis of ecosystem services at the farm scale during the transition to organic production. Another considers the landscape interactions of water movement from agricultural tailwater to wetlands. The third deals with regional-scale issues that are pertinent to several types of agricultural landscapes in the Delta region.

Transition to organic agriculture

Organic agriculture is defined by both state (California Organic Foods Act) and federal (National Organic Program) policies as using only organically-approved fertilizers, pesticides and amendments, and adopting other practices that increase agricultural sustainability. Most of the management practices used in organic agriculture in California have been developed by growers with minor backup from public-sector research, often using traditional approaches, e.g., crop diversity, crop rotation, and inputs of crop residues and animal manures. Until recently, organic agriculture in California has been in small-scale operations, with an average of 32, 78, and 109 acres/grower in 1995, 2000, and 2005 (Klonsky et al. 2002, Klonsky and Richter 2007). Total acreage has increased from 46,258 to 194,907 acres in the same time frame. Even in 1995-98, however, nearly 50% of the value of organic production was captured by the 1% of growers who grossed over $1 million annually (Klonsky et al. 2002). What management practices could make organic production feasible and sustainable for more large-scale producers in order to provide provisioning and regulating/supporting services across California agricultural landscapes? Answering this question requires that a wide range of services be assessed across the spatial and temporal scales that represent decision-making options of organic growers at the farm scale.

In the Salinas Valley, our interdisciplinary group from University of California conducted a study to investigate production and environmental quality issues during transition to organic production by Tanimura and Antle, Inc., a large conventional producer of cool-season vegetables. Changes in crops, soils, pests and diseases, weeds, and management practices were tracked by monitoring 81 points on two ranches at each crop harvest during the three-year transition (Smukler et al. ms. submitted.). Single blocks of ~10 ha were divided into many plantings of many different crops and cover crops (Figure 3), greatly increasing diversity compared to conventional practices. It was

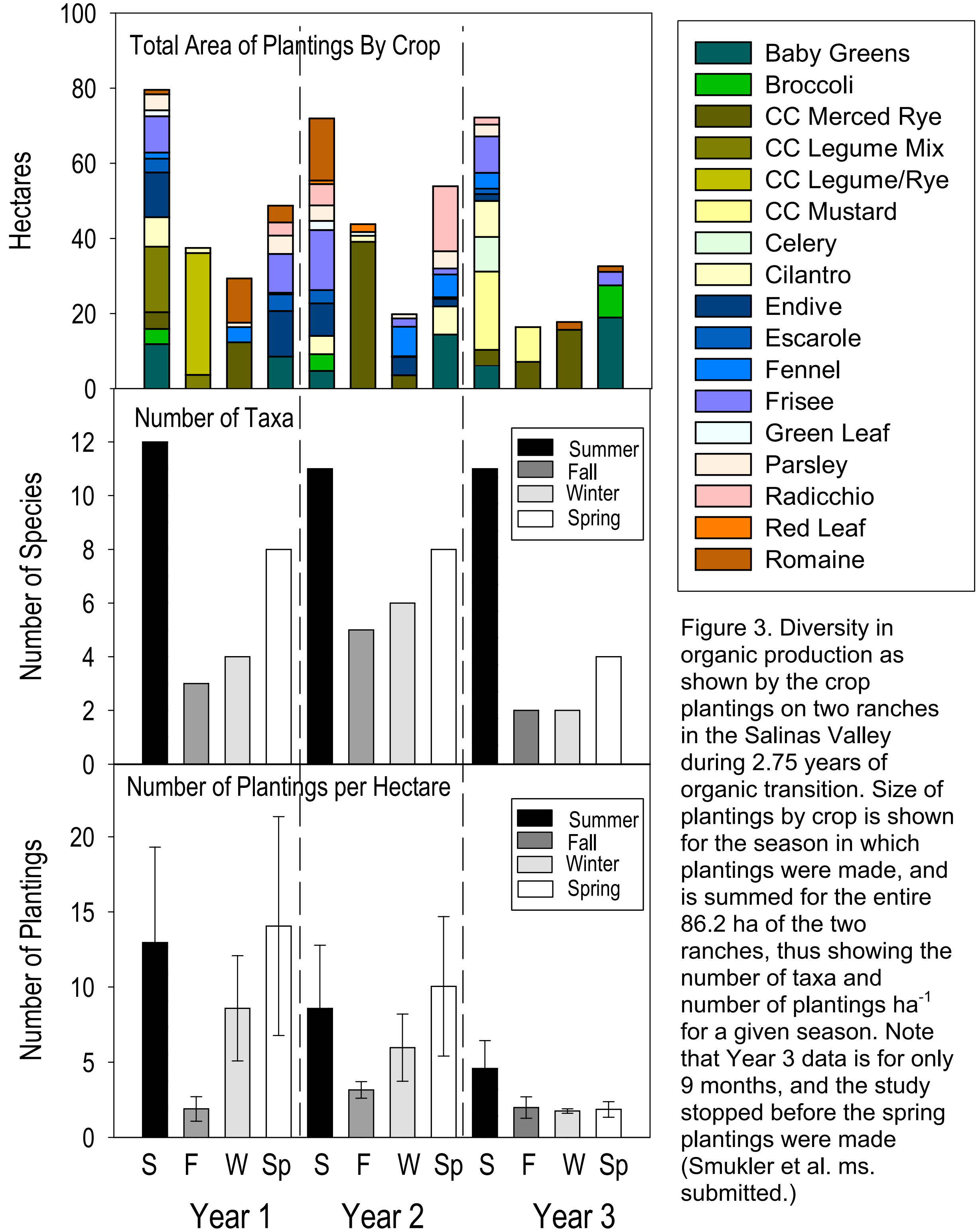


Figure 3. Diversity in organic production as shown by the crop plantings on two ranches in the Salinas Valley during 2.75 years of organic transition. Size of plantings by crop is shown for the season in which plantings were made, and is summed for the entire 86.2 ha of the two ranches, thus showing the number of taxa and number of plantings ha^{-1} for a given season. Note that Year 3 data is for only 9 months, and the study stopped before the spring plantings were made (Smukler et al. ms. submitted.)

possible to identify the management practices and conditions most conducive to high yields (e.g., specific taxa), lower pest pressure (e.g., proximity to ranch edges), and greater environmental quality (e.g., diverse nutrient input sources), since the design provided a large data set and a variety of different conditions that were conducive to analysis by multivariate methods (Classification and Regression Trees and Canonical Correspondence Analysis).

Changes in management practices during the transition period showed a distinct learning curve in relation to nutrients (i.e., increased soluble organic fertilizer additions) and pest management (i.e., decreased use of organic pesticides). Overall, there was a gradual increase in relative yields, an improvement in soil biological indicators for soil health, generally adequate plant available N with reduced soil nitrate and less leaching potential, and low levels of insect pests, diseases and weeds without the use of environmentally-harmful pesticides. These outcomes are beneficial for ecosystem services at the farm scale, but also have positive repercussions for health and well-being of the public at large.

One of the major tradeoffs, however, was that management was more dynamic and time-consuming than conventional production, and economic analysis was not straightforward, since the company benefited from combining sales of organic and conventional products. The design of this project, at the growers' request, took a descriptive exploratory approach, rather than an experimental approach with specific agronomic treatments that would have been difficult to select ahead. This approach was able to capture innovation and adaptive management, and showed that indicators of a range of provisioning and regulating/supporting ecosystem services increased through time.

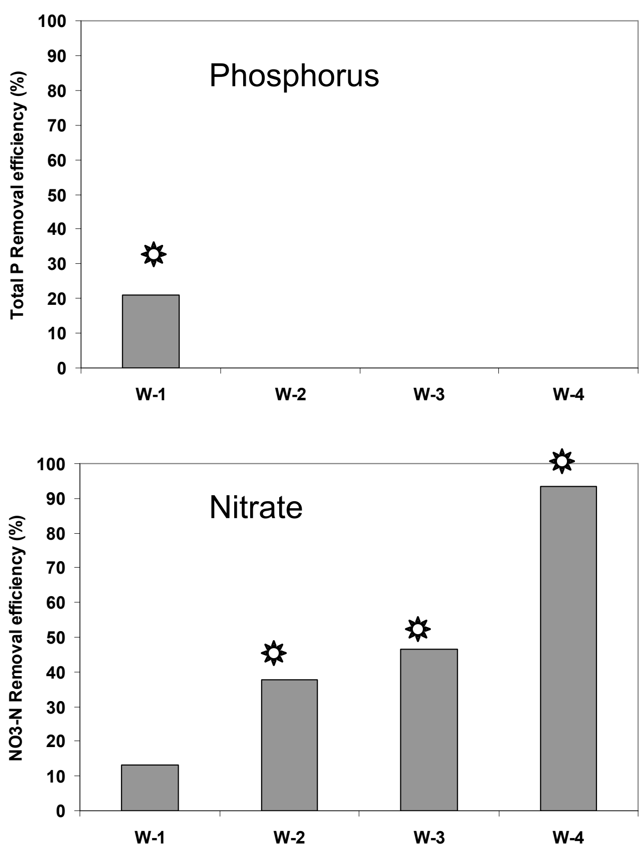
This study demonstrates that intense research effort is required to demonstrate a range of ecosystem services at the farm scale, and spatial and temporal variability in responses. Organic farming can use many types of approaches, which change according to local site environmental conditions, markets, and availability of technology. Thus, it is not easy to generalize about the benefits from a range of ecosystem services that are provided by organic agriculture in California. This brings up an important question for policy: how much monitoring is necessary to compensate or reward land users for provisioning of ecosystem services?

Constructed wetlands to improve water quality from irrigation tailwater

As a regulatory body, the State Water Resource Control Board has implemented a state-wide water quality monitoring program for irrigated agriculture. Those regions that exceed water quality standards must emplace management practices to mitigate non-point source pollution. A University of California case study in the Central Valley is investigating the efficacy of constructed flow-through wetlands to intercept irrigation return flows and filter water quality contaminants ultimately destined for the San Joaquin River (T. O'Geen, pers. comm.). The project was participatory in that three of the wetlands were constructed by government agencies (NRCS and Dept. of Fish and Wildlife), and one is privately owned by a duck hunter.

Preliminary results demonstrate that wetlands can improve water quality of irrigation tailwaters. A suite of water quality constituents were monitored at input and output locations of four wetlands constructed with land planing and vegetation change. Sites were chosen to compare differences in size (ranging from 2.3 to 150 ha) and design (two open water designs vs. two with dendritic networks of micro-highs and lows). Pyrethroid pesticides (up to 95%) and sediment (90-97%) were effectively removed in all of the wetlands. Seasonal removal efficiencies for nitrate, however, were variable, ranging from 10% to 50% in the smaller wetlands and over 90% in the largest wetland (Figure 4). Three of the four sites were a source of phosphorus likely because vegetation was not established. Plant uptake is the primary mechanism for P removal. The four wetlands were quite variable in performance for recovery of these nutrients, and although results from other important constituents, e.g., dissolved organic carbon and nitrogen, are not yet available, some of these constructed wetlands showed potential to be excellent sinks for sediment, pyrethroids, and nutrients, and represent the last opportunity for treatment before tailwaters are re-circulated back to the San Joaquin River.

Figure 4. Variation in phosphorus and nitrate-N removal efficiency, based on differences in concentration in inflow vs. outflow, in four constructed wetlands (W-1 through W-4) for irrigation tailwater delivered to the San Joaquin River. *=wetlands showed a significant difference between seasonal input and output means (Tukey's Mean Separation procedure). Figure provided by A.T. O'Geen (University of California Davis).



But wetlands also can have adverse effects on water quality. Constructed wetlands can provide habitat for algae, which contribute to biological oxygen demand and eutrophication. This is of critical interest because the San Joaquin River currently witnesses episodes of low dissolved oxygen that impede spawning salmon. Thus, flow-through wetlands could simply serve as an incubator, transforming nutrients to algal biomass, resulting in no beneficial effect on dissolved oxygen levels in the lower San Joaquin River. Monitoring of chlorophyll-a, a bio-indicator of algae, indicates that algae concentration decreases dramatically once a canopy of emergent vegetation forms within the constructed wetlands that intercept incoming light. These issues indicate that there must be compromises among stakeholders with different interests that are based on the scientific understanding of ecosystem processes.

Constructed wetlands provide an example of the need for scientific information on ecosystem processes to satisfy different regulatory goals. Preliminary data suggest that there are tradeoffs between managing for contaminant clean up vs. wildlife habitat. These data also suggest that adaptive management is likely to be important for the long-term success of managing for multiple services, because of the variability among constructed wetlands in nutrient outflows. It will be expensive to monitor environmental processes and subsequently alter practices, e.g., changes in vegetation management and in the biodiversity of vegetation to reduce algae and eutrophication. Compromises from various types of stakeholders, e.g., growers, government agencies, hunters, and fisherman, would be needed at each step in the adaptive management process.

Water Supply vs. Environmental Goals in the Sacramento-San Joaquin Delta

A recent analysis of alternatives for the Sacramento-San Joaquin Delta, which supplies water to agricultural and urban sectors in Southern California, was developed in an interdisciplinary study by several University of California scientists and the Public Policy Institute of California (PPIC) (Lund et al. 2007). The Delta is considered in crisis for three reasons: the levee system is in poor condition; 2) several native fish species are declining; and 3) the governing institution, CALFED, is suffering from financial and political stress (Howitt 2007). An unexpected major collapse in levees could cost $40 billion, and have widespread effects on drinking and irrigation water. Participating environmental scientists found that native species would be favored more than invasive species if salinity levels in the Delta were allowed to fluctuate rather than be held constant as dictated in the current long-term policy of maintaining fresh water. Economic-engineering models were used to examine the effects of salinity or levee failure on the Delta's agricultural economy.

Scenarios were developed in the study, and nine alternative policies were explored for their effects on water supply and agriculture, and are shown in condensed form in Table 1 (Lund et al. 2007). As a result of analyzing the tradeoffs between investment costs, improved environment for native species, and Delta agriculture, the study group concluded that the only viable alternatives were those that have some degree of salinity fluctuation in the Delta, but with different levels of investment in infrastructure and capacity for water deliveries. The management options considered are levee replacement, ecosystem restoration, flood control, and island land management. By deciding on the preferred alternative based on technical analysis by various stakeholders, action would be set in place, and plans for adaptive management could be made. This was favored over piecemeal solutions that could increase the risk of flooding, loss of wildlife habitat, and the deterioration of water quality due to lack of long-term planning for multifunctionality of ecosystem services in the Delta. In terms of solutions, one of the key messages was that CALFED policy should change to negotiate tradeoffs ahead of catastrophes. Some options would be eliminated and the stakeholders who lose out from wrong management decisions, would be compensated. This was considered preferable to aiming for complete consensus, which was recognized as unachievable by the study group.

Table 1. Scenario planning for nine alternatives for the management of the Sacramento-San Joaquin Delta, as projected by Lund et al. (2007) (no copyright permission obtained).

Alternatives	Summary Evaluation	Rationale
Freshwater Delta		
1. Levees as Usual (current or increased effort)	Eliminate	Current and foreseeable investments at best continue a risky situation; other “soft landing” approaches are more promising; not sustainable in any sense.
2. Fortress Delta (Dutch standards)	Eliminate	Great expense; unable to resolve important ecosystem issues.
3. Seaward Saltwater Barrier	Eliminate	Great expense; profoundly undesirable ecosystem performance; water quality risks.
Fluctuating Delta		
4. Peripheral Canal Plus	Consider	Environmental performance uncertain but promising; good water export reliability; large capital investment.
5. South Delta Restoration Aqueduct	Consider	Environmental performance uncertain but more adaptable than Peripheral Canal Plus; water delivery promising for exports and in-Delta uses; large capital investment.
6. Armored-Island Aqueduct	Consider	Environmental performance likely poor unless carefully designed; water delivery promising; large capital investment.
Reduced-Exports Delta		
7. Opportunistic Delta	Consider	Expenses and risks shift to water-importing areas; relatively low capital investment; environmental effectiveness unclear
8. Eco-Delta	Consider	Initial financial costs likely to be very high; long-term benefits potentially high if Delta becomes park/open space/endangered species refuge
9. Abandoned Delta	Eliminate	Poor overall economic and environmental performance; southern Delta water quality problems; like Alternative #1, without benefits

V. CONCLUSIONS

Throughout this paper, a recurrent theme has been multifunctionality in California’s agricultural landscapes, i.e., the joint production of provisioning, regulating, supporting and cultural ecosystem services. There has been a strong emphasis on the need for interdisciplinary projects that involve participation by stakeholders, so that innovation can be accurately appraised, and that adaptive management can proceed effectively. Developing collaborative mechanisms requires considerable effort, especially among people who do not share common views. Cultivating these teams is an art and takes time.

The complexity of the issues surrounding multifunctionality of agricultural landscapes suggests that a project uses a set of research approaches. Some of the research approaches were described in the above examples: exploratory or survey approaches that utilize multivariate analysis techniques, landscape-level field experiments, modeling, and scenario planning. These are all techniques for dealing with complexity, and their results can potentially build upon each other to determine the various costs and benefits for management options in providing multifunctional ecosystem services.

Cultural services have not been emphasized in this paper, but deserve a comment. Aspects of human well-being that are derived from the environment, such as social bonds from community-based stewardship projects, family ties to land, personal satisfaction derived from land stewardship, and aesthetic value and spiritual fulfillment from open spaces, need more attention. There is a need for biophysical and social scientists to collaborate to develop valuation systems for cultural services.

One of the biggest challenges for increasing agroecosystem services in California is reconciling different temporal scales. Short-range planning is needed to keep farmers in business, but long-range planning will better meet the needs of society as whole. Two issues are of major importance over the long-term. One is urbanization, which is likely to result in the loss of up to 15% of the prime agricultural land in the San Joaquin Valley counties, and 50% of the remaining agricultural land in the coastal counties by 2050 (Landis and Reilly 2004). The other issue is global warming. Impacts will differ according to the amount of GHG emissions that occur during the next century, and thus, predictions of provisioning and regulating/supporting services in California vary according to different warming scenarios (Cavagnaro et al. 2005). Mitigation of GHG emissions to comply with AB32, the 'Global Warming Solutions Act' will likely change land management practices, ideally in ways that increase the joint production of other environmental services, e.g., increased C and N sequestration to reduce carbon dioxide and nitrous oxide emissions can also improve soil and water quality. Adaptation will be required to cope with changes in water availability and water deliveries, heat, and pests. The uncertainty associated with climate change makes a strong case for research and demonstration programs that embrace complexity, employ interdisciplinary teams of researchers and stakeholders, and emphasize adaptive management to provide a range of ecosystem services in agricultural landscapes.

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