Agric Hum Values (2011) 28:483–496
DOI 10.1007/s10460-010-9288-4

The decline of public interest agricultural science and the dubious future of crop biological control in California

Keith D. Warner · Kent M. Daane · Christina M. Getz · Stephen P. Maurano · Sandra Calderon · Kathleen A. Powers

Accepted: 7 September 2010 / Published online: 9 October 2010

Abstract Drawing from a four-year study of US science institutions that support biological control of arthropods, this article examines the decline in biological control institutional capacity in California within the context of both declining public interest science and declining agricultural research activism. After explaining how debates over the public interest character of biological control science have shaped institutions in California, we use scientometric methods to assess the present status and trends in biological control programs within both the University of California Land Grant System and the California Department of Food and Agriculture. We present available data on the number of scientific positions and the types of positions to discuss the impact on the amount of public interest research on biological control in California. We use sociograms to depict how biological control science networks have been reconfigured over time. Our quantitative and qualitative analyses indicate that the following factors contributed to the decline of biological control science in California over the 45-year period analyzed: (1) the institutional reconfiguration of university research priorities; (2) the fraying networks within and increasing specialization of biological control science; (3) the transformation of the social organization of the life science work, including privatization; and (4) the abandonment of this thematic area by civil society activist groups. This broad array of forces suggests that biological control, as a public interest science, will require a deliberate intervention, based on advocacy of clear public interest criteria.

Keywords Pest control · Agricultural science · Biological control · Public interest science · Institutional capacity · Social networks

Abbreviations

CDFA	California Department of Food and Agriculture
CE	Cooperative Extension
IPM	Integrated pest management
LGU	Land grant university
PCA	Pest Control Advisor
SRAs	Staff research assistants
SYs	Scientist years
UC	University of California
USDA	United States Department of Agriculture

K. D. Warner (✉)
Department of Religious Studies and Center for Science, Technology, and Society, Santa Clara University, Santa Clara, CA 95053, USA
e-mail: kwarner@scu.edu; kdwarner@gmail.com

K. M. Daane · C. M. Getz
Department of Environmental Science, Policy and Management, University of California, Berkeley, CA 94720-3114, USA

S. P. Maurano · S. Calderon · K. A. Powers
Environmental Studies Institute, Santa Clara University, Santa Clara, CA 95053, USA

Introduction

The commercialization of American university science has received substantial scholarly attention over the past decade, particularly the conceptual framing of changes to cultural values within specific scientific disciplines (Delborne 2008; Kleinman 2003; Krimsky 2003) and the evolution of broader institutional pressures on university research agendas (Croissant and Restivo 2001; Glenna et al. 2007a, b; Rudy et al. 2007; Warner 2007). This scholarship shares a broad consensus opinion that commercial pressures have favored private sector science within public universities, that these pressures have progressively increased over time, and that this trend is problematic from the perspective of academic values (Lacy and Glenna 2006). Krimsky encapsulates this line of critique by stating that "commercial not social priorities" dictate scientists' research programs (Krimsky 2003, p. 179). This scholarship has demonstrated how commercialization rewards what research is now conducted (Rudy et al. 2007), but few studies have investigated research that is abandoned. This lacuna can be addressed by investigating an orphaned science, a field of research for which there are now fewer incentives as a result of commercialization, such as crop biological control.

The consensus critique of the commercialization process further suggests that the public's interest is poorly served by research activities commonly undertaken at public universities, in part because economic forces are reconfiguring professional incentives to weigh more heavily towards serving private than public research interests. This concern, however, is not necessarily accepted by all university leadership; many administrators do interpret their mission as contributing towards the public good. This includes encouraging partnerships with private firms and the commercialization of research discoveries (Glenna et al. 2007a). Nevertheless, the American Land Grant University (LGU) system was created with public funds and an explicit mission to serve the public (McDowell 2001). For this reason, studies of current trends in environmental and agricultural research at LGUs are warranted to ensure that the valuable public interest science they are directed to provide does indeed continue.

The founders of the Agriculture, Food, and Human Values Society and its journal have devoted significant scholarly attention to the LGU system and its mission (Busch and Lacy 1983; Buttel et al. 1990; Dahlberg and Koc 1999; Hadwiger 1982), and competing agendas within the LGUs (see Rudy et al. 2007). One of the first public critiques of LGU's modern-era agricultural research was in Rachel Carson's *Silent spring* (1962). Carson suggested that entomologists working on pesticide controls and their institutions caused harm to humanity and nature. Carson further argued that biological control of insect pests was a socially and environmentally preferable alternative to toxic pesticides, and that this pest management strategy could be successful if scientific institutions supported its development. In *Hard tomatoes, hard times*, Hightower (1973) took agricultural sciences to task for their negative socio-environmental impacts, and explicitly focused criticism on the LGU system for its failure to fulfill its public interest mission.

Subsequent critical reviews of agricultural science have often examined the social factors influencing formulation of research agendas, whether commercial (Kloppenburg 2004), scientific (Perkins 1982), or civil society advocacy groups (e.g., Campbell 2001). Buttel (2005) named the latter as "Hightowerism," which he defined as the activist movement critical of public agricultural science institutions and the technologies they created. For example, inspired by Hightower, activist groups sued the University of California in 1979, charging that its research programs failed to fulfill its LGU charter for the public good (Friedland 1991). Buttel noted that Hightowerism was relatively short lived, lasting less than two decades, despite predictions of its longevity. Hightowerism then bifurcated into two movements: one focused on agricultural sustainability and the other on anti-transgenic/anti-globalization. Since the 1980s, agricultural research activism has markedly declined, in large part because LGU administrators have successfully repelled efforts to influence research funding (Buttel 2005; Campbell 2001).

Agricultural research activism has often deployed a "corruption" narrative that implies the current agricultural research and extension agendas of LGU's have been corrupted by private interest science, while the original mission goals were more closely aligned with democratic ideals. Activists' use of a "corruption" narrative depends upon an idealized "Golden Age" of agricultural science that served the needs of family farmers (Buttel 2005). The argument continues today, with LGU administrators often implying that current research programs serve the global public interest through the development of better crops, medicines, and alternative energy sources, and through addressing environmental problems such as climate change. Nevertheless, the Golden Age narrative has not altered agricultural research activism claims that LGUs had, in the past, better served the needs of family farmers, and this argument became a reference point for those who later redeveloped a critique based on the corruption narrative. There is clear evidence, however, that LGUs have long served private commercial interests, as far back as the early twentieth century with the development of early pesticides (Stoll 1995, 1998).

Echoing Carson and Hightower, van den Bosch's (1978) *The pesticide conspiracy* claimed that the commercial interests of insecticide manufacturers purposefully sabotaged publicly funded integrated pest management (IPM) research and strategies. Perkins (1982) described this idea as the "corruption" hypothesis, which was repeated by Jennings (1997) in his critique of the University of California (UC) for eliminating alternative agriculture institutions. Kleinman (2003) cautioned, however, against the imposition of simplistic corruption narratives based on the commercialization of the life sciences. He provided a more nuanced portrait of how commercial values shape the culture of research, and exert tacit influence on public university science agendas. Still, the evolution of agricultural science away from a primarily organism-based research (e.g., biological control) towards one that more heavily values molecular-based research (e.g., transgenic or "GMOs") has had the paradoxical effect of fueling arguments that LGUs have abandoned public service interests while simultaneously insulating their research agenda from public critique (Buttel 2005).

In contrast to private science, as critiqued above, Raffensperger et al. (1999) propose three criteria to define public interest science:

1. Information and technologies are developed with collaboration or advice from an active citizenry;
2. Information and technologies are made freely available (not proprietary or patented); and
3. The primary, direct beneficiaries are society as a whole or specific populations or entities unable to carry out research on their own behalf.

In this definition, public interest science necessarily consists of both a participatory social process and a non-commodity product. Private interest science is directed at the production of proprietary knowledge and technology and in the service of private, for-profit firms. Chemical weed and pest control research directly benefits the manufacturers and retailers; it benefits growers indirectly and at cost. In contrast, public interest science is directed at the production of non-proprietary knowledge and technology that directly benefits a wide range of citizens, and the environment. Biological control (bio-control) of arthropod pests (primarily insects and mites) can be understood as a public interest science because it fulfills Raffensperger et al.'s criteria above.

Here, we evaluate Perkins' corruption hypothesis by investigating the trends in bio-control programs at the University of California's LGU campuses since the publication of *Silent spring*, as one indicator of the decline of public interest agricultural science. We begin with a description of how the public interest character of bio-control programs helped shaped California's LGU institutions (Berkeley, Riverside, and Davis), as well as the global practice of bio-control. We then provide original data that demonstrate the decline in bio-control programs over the 45-year period, and we interpret these results in light of Raffensperger et al.'s criteria for public interest sciences. We conclude by describing the fraying of networks that support bio-control programs, and propose conditions and strategies that have the potential to reverse this decline. Methodologically, we draw from the field of Science, Technology, and Society (STS) and scientometrics, or the quantitative measure and analysis of scientific activity within institutions and networks (Callon et al. 1986; Leydesdorff 2001). Prior studies have decried the decline in public university investment into bio-control (Jennings 1997), but this is the first to document this claim.

Biological control as a public interest science in California

Biological control is the use of introduced or manipulated natural enemies (e.g., lady beetles) to control arthropod pests (Huffaker and Messenger 1976). There are three practical forms of bio-control that are most often cited, with each dependent on the activity of natural enemies and based in principles of insect ecology. First, classical bio-control is the introduction of novel natural enemies to control exotic pests (De Bach and Schlinger 1964). Second, augmentative bio-control is the rearing or collection of natural enemies for mass release in fields and greenhouses (Huffaker and Messenger 1976; Ridgway and Inscoe 1998), which can be cost effective for some pest species in North American field crops (Warner and Getz 2007), but it is most often successfully used in glasshouse systems in Europe. Third, conservation bio-control manipulates agricultural habitat, such as the addition of cover cropping, to favor resident natural enemies (Altieri 1984; Andow 1991; Gurr et al. 2003). Other schools of bio-control embrace a different typology of forms (e.g., Eilenberg and Hokkanen 2006); however, most have a founding principle based in elements of insect ecology and a reduction in broad spectrum pesticides.

California entomologists were not the only or first agriculturists to practice biological control programs, but certainly played a key role in its development as an applied practice and research field. The term biological control was first used by UC Riverside's Harry Scott Smith (1919) but bio-control practice had earlier entered the public's popular imagination in 1888 after control of the exotic cottony cushiony scale in California citrus by the introduction of the vedalia beetle from Australia (Caltagirone 1981). The program was organized by C.V. Riley, Chief Entomologist for the United States Department of Agriculture (USDA), with moral support from the California State Board of Horticulture. The introduction of this small beetle so effectively controlled the pest that it virtually disappeared from orchards (Sawyer 1996). The history of this program is itself intriguing, filled with personal conflicts, policy and scientific arguments, and even the devious use of government funds to send the collector, A. Koebele, to Australia (Caltagirone and Doutt 1989; Doutt 1964). To continue such efforts, in part through pressure from citrus growers, the State of California hired George Compere in 1899 to conduct foreign exploration for natural enemies of other exotic pests. California was the first state to develop such a dedicated bio-control program and has been a global leader in the development of this field (Sawyer 1996). However other bio-control programs were initiated in other regions, such as the 1882 importation of the egg parasitoid *Trichogramma* for control of the European currant sawfly in Canada (Turnbull and Chant 1961) and the 1903 initiation of natural enemy importation to control prickly pear cactus in Australia (Wilson 1960).

Following the spectacular success of the vedalia beetle was a period described by Compere (1969) when "enthusiasm for bio-control was unrestrained." In the early 1900s, the "ladybird fantasy"—the belief that all pest problems could be solved by these insectivorous beetles (Lounsburyi 1940)—led both public and private sectors to import and release inappropriate insect species around the world, including even some pest species inserted in the shipments as food for the beetles. To improve bio-control activities, California established a State Insectary in Sacramento in 1913, directed by H.S. Smith (Simmonds et al. 1976). Professor Smith had worked for the US Bureau of Entomology in Massachusetts, and were it not for his close ties to the USDA, bio-control work in California may have been stopped by the federal government (Doutt 1964). In 1923, Smith moved the unit to the Citrus Experiment Station at UC Riverside, where it was renamed as the Division of Beneficial Insect Investigations. In 1945 a second unit was established at the UC Biological Control Experiment Station in Albany (near UC Berkeley). These units later became the Division of Biological Control with Smith as chairman in 1947. The Division of Biological Control became the Departments of Biological Control at UC Riverside and UC Berkeley in 1954.

Social, environmental and institutional forces favored the science and practice of bio-control in California agriculture (Baker 1988; Stoll 1998; Warner 2007). By the time *Silent spring* was published in 1962, the UC Departments of Biological Control were world renowned leaders in the fields of bio-control, insect ecology, and arthropod pest management. A great number of the graduate students produced during this period became research leaders at other University and government agencies, continuing the "California School" of bio-control. Nevertheless, a combination of internal disputes and external pressures at both the Riverside and Berkeley campuses began the slow dismantling of both Departments. On the Riverside campus, in 1969 the Department of Biological Control became the Division of Biological Control, which was folded within the Department of Entomology. According to one of its faculty (http://www.faculty.ucr.edu/~legneref/), "The Division of Biological Control gradually became dominated by chemical control oriented faculty in the Department of Entomology." By 1989, UC Riverside's Division of Biological Control was abolished. On the Berkeley campus a similar path was taken, albeit a decade later in its cadence, with the Department becoming a Division of the Department of Entomology in 1969, and later to become the Center of Biological Control within the Department of Environmental Science, Policy, and Management in 1992.

This brief history of California bio-control is incomplete, and certainly there were many other organizations participating. Staff and students from the University of California formed many of the first commercial insectaries (a foundation of the augmentation form in bio-control), successful Pest Control Advisor (PCA) firms, and the Association of Applied Insect Ecologists, which fosters pest control practices based on the principles of insect ecology and IPM. The California Department of Food and Agriculture (CDFA) reestablished the state insectary operations in Sacramento, in 1974, to help rear and release effective bio-control agents (CDFA Biological Control Program). The USDA housed an active weed bio-control unit at the Western Regional Research Center in Albany, which had close working ties with the UC and CDFA programs. This USDA unit continues today as the Exotic and Invasive Weeds Research Units. UC researchers also created an infrastructure of facilities (e.g., insectary and quarantine), foreign contacts for exploration, graduate students and post doctorate researchers, and grower and extension cooperators for field release of natural enemies (van den Bosch et al. 1982). Their strong esprit de corps (Sawyer 1996) led them to create networks that included research directors of commodity boards, county agricultural commissioners, and the above-mentioned CDFA and USDA bio-control personnel.

Even with this apparently strong network across university, state, federal and private entities, the late 1970s marked the initial period of declining administrative and public support for bio-control in California. Similarly, across the country, the introduction of effective and often toxic insecticides—such as organochlorines (e.g., DDT) and organophosphates (e.g., parathion)—during the post-World War II period, corresponded with a contraction in the science and practice of bio-control, as measured by the number of successful introductions (Gurr et al. 2000). Economic entomologists embraced pesticide technologies, which soon dominated pest control research programs at the USDA and LGUs (Palladino 1996; Perkins 1982). Nevertheless, during this same period of declining support, researchers continued to document the success of past bio-control programs and develop new programs throughout the world (e.g., Altieri 2002; Ehler 2005; Greathead and Neuenschwander 2003; Turnbull and Chant 1961; Viggiani 2000), thereby proving the value of bio-control.

Leading scientists in the California school had argued for bio-control on the basis of practicality and the potential to create lasting pest control solutions. Their critique of broad-spectrum insecticides focused primarily on materials that harm natural enemies (e.g., Luck and Dahlsten 1975) rather than pesticides' adverse impacts on public health or the environment. *The pesticide conspiracy* was a notable exception. Van den Bosch (1978) attacked the political influence of pesticide industries on agricultural science and extension. Although he did not use the term "public interest science," he advocated bio-control and IPM as socially and environmentally preferable, and more consistent with the public charter of LGUs. Van den Bosch used highly charged language to appeal for greater public engagement in supporting pesticide alternatives. Echoing Carson and Hightower, van den Bosch claimed that the commercial interests of insecticide manufacturers undermined the ability of publicly funded entomologists to devise and extend ecologically rational IPM strategies. His book was published during the rise of Hightowerism, and it fed farmer and activist interest in the 1979 lawsuit against UC (Campbell 2001; Warner 2007).

Van den Bosch's arguments were relayed by civil society groups for more than 25 years. Perkins (1982) described these arguments as van den Bosch's "corruption theme," and this description was extended by Jennings (1997). Other bio-control scientists have extended the corruption theme from pesticides to transgenic engineering research trumping bio-control programs (Van Driesche and Ferro 1990). As we will delineate below, the UC abolished the two dedicated UC bio-control institutions, at Riverside in 1989 and Berkeley in 1992. This provided evidence, for some, to the corruption theme. Jennings (1997) argued that UC suppressed these two institutions because they offered support to scientists and activists who critiqued LGU research priorities and pesticide-intensive agriculture. He asserted that bio-control and transgenic engineering rest on alternative scientific paradigms substantially shaped by competing assumptions regarding whom LGU science should serve. Scholarly advocates for bio-control have consistently asserted that if more research funding were provided, this form of pest management could redress the gap between its potential and actual achievement (Jennings 1997; van den Bosch 1978; Van Driesche and Ferro 1990). Prior analysis (Warner et al. 2009) of bio-control agent release records in California indicates a clear downward trajectory over the past two decades, suggesting a correlation between the decline of both institutions and metrics of practice.

Characterizing trends in scientific institutional capacity

To assess historical trends that led to the present status of bio-control in California, we adapted the methods of Perkins and Garcia (1999) to analyze the UC and CDFA bio-control programs. Information was gathered on the number of scientific positions (measured in scientist-years, or SYs), the types of positions (bio-control versus other activities), research activities, and reported programmatic successes. This study does not report on funding trends, since these data were not always available. To identify the broader forces shaping these institutions, we interviewed five UC scientists, four county agricultural commissioners, six commodity board research directors, and 13 scientists in other universities or state agencies. Interviews were conducted from 2002–2008. Note that we have not included the California-based USDA bio-control scientists in the analyses; these researchers were primarily involved with weed bio-control. The UC historically exercised more autonomy over its agricultural science, relative to other states, and thus the USDA was not as involved with bio-control programs targeting insect pests (Sawyer 1990).

Bio-control researchers in California

The scientific activities of UC entomology faculty at Riverside, Berkeley, and Davis (the UC's three LGU campuses) were categorized for the period 1962–2006 to assess their research in bio-control relative to other interests. We included all fulltime Academic Senate and Cooperative Extension (CE) faculty. Nematologists were included in the general category of entomologists. We excluded emeritus and adjunct (part-time) faculty as well as staff research assistants (SRA), which we acknowledge provided vital support for bio-control research. We also excluded faculty for whom dates of employment were missing or ambiguous. This method resulted in a population of 246 scientists. Scientific activities were determined from the following hierarchy of data sources, from most preferable (A) to least preferable (D). If data from source A were unavailable, then we would turn to B, then C, then D; in several cases we examined multiple types of data.

A. Survey questionnaire querying about the types and numbers of bio-control projects and publications. This was possible only for scientists currently on faculty at the 3 departments. The survey of contemporary UC entomology faculty was conducted by email and the Internet in May 2007. Of the current 83 faculty, 32 responded, for a response rate of 38.5%.
B. Curriculum Vitae (CV).
C. Obituaries. These scientific obituaries, prepared by colleagues or fellow members of a department, provide a summary narrative of the research agenda of the scientist.
D. Abbreviated CVs, campus catalogues or departmental files.

We gathered sufficient data to code 199 of the 246 faculty. Interviews with eight UC faculty provided further historical perspective and interpretation of these records. We then analyzed individual records of these 199 researchers to determine their involvement in bio-control, using the coding system of Table 1. We evaluated SYs at the California Department of Food and Agriculture (CDFA) Biological Control Program, drawing from annual program reports from 1993 to 2004.

Results from this analysis show that of the 199 coded UC scientists, 72 participated in bio-control research, coded 1, 2, or 3 (Fig. 1A). There were clear historical changes, with total entomology SYs in the UC system peaking above 110 in the mid-1980s and then dropping dramatically in the early 1990s. This trend was most evident at UC Berkeley, where the number of entomology positions dropped from 52 in 1984 to 21 in 1996.

Of particular interest for this study was the numerical change in numbers of active bio-control researchers (codes 1 and 2). During this study period, UC had 19 dedicated (code 1) and 25 partial (code 2) bio-control faculty and/or CE specialists. These faculty members were housed chiefly at Berkeley and Riverside, in the Departments or Divisions of Biological Control, while there was one dedicated and several partial bio-control faculty members on the Davis campus. The number of UC entomologists coded 1 and 2 rose from the mid-teens in the 1960s to the high teens in the 1970s to the high twenties in the 1980s, but then declined to 17 by 2006. Between 1965 and 1984, the number of entomologists coded 1 fluctuated between 12 and 15; this number declined to 6 by 2006 and of these, and half are slated for retirement within the next few years.

The number of SYs that had research programs described as partial bio-control (code 2) remained about the same over the period of study, while the number of SYs supportive (code 3) of bio-control increased substantially after 1980. With the categorization used, to qualify as "supportive" only one published article that addressed some aspect of bio-control was needed. The increase in code 3 scientists took place during the same period as the decrease of SYs dedicated (code 1) to bio-control. This period, during the 1980s, may be key to understanding the changes to public interest research in bio-control. For example, changes within California's LGUs placed greater pressure on scientists to procure research funding to operate their laboratories; newly hired scientists in the bio-control units developed research programs based more in conservation, insect ecology, or insect modeling rather than classical bio-control; and promotions now had a greater emphasis on publications, college-based committee assignments, and instruction. This "multi-purpose" faculty member of the bio-control units was often categorized as a code 2 or 3.

The CDFA Biological Control Program began in 1974 with 4 SYs and rose as high as 14 in 2001, but has declined since that period (Fig. 1B). A part of this decline was from budget reductions, another part was from the reassignment of personnel working on the bio-control of specific projects, such as the CDFA insectary operations for parasitoids of invasive insects, such as the glassy-winged sharpshooter. For this study, we coded all CDFA personnel as dedicated bio-control, with scientists split almost evenly among insect and weed pest targets. Here, we note that the unit was created to help implement bio-control programs—a role characterized in the LGUs by Cooperative Extension (CE) personnel. Not described in our assessment of campus-based entomologists in the LGUs is the reduction in county-based CE personnel, which had taken an even greater reduction in numbers during the 1990s and 2000s. With the reduction of support staff at the UC bio-control units and the reduction of county-based personnel to assist with field implementation of developed projects, the role of the CDFA Biological Control Program and its insectary became even more critical in the implementation of bio-control programs. Members of this unit were freed from many of the responsibilities of faculty at the LGUs (e.g., teaching, committee service) that competed with the development of bio-control programs, but they also lacked academic infrastructural support (e.g., quarantine) or support (e.g., graduate students) to develop large, independent programs for each SY.

Table 1 Coding scientific activities for bio-control research and extension personnel at the University of California and California Department of Food and Agriculture, 1962–2006

Code	Description
1. Dedicated bio-control scientist	These have met one of the following criteria: publishing 2 or more major books on bio-control; having >30 publications on this topic; or >30% of 50 or more publications
2. Partial bio-control scientist	This category designates scientists who have devoted a considerable portion of their research to bio-control, such as foreign exploration. They have published 4 or more papers in bio-control
3. Scientist supportive of bio-control	This category designated scientists who have done some bio-control research, but it has not been the major emphasis, with only 1–3 publications concerning a bio-control topic. Many scientists working on IPM fall into this category
4. Scientist not involved in bio-control	These have not conducted any measurable bio-control research

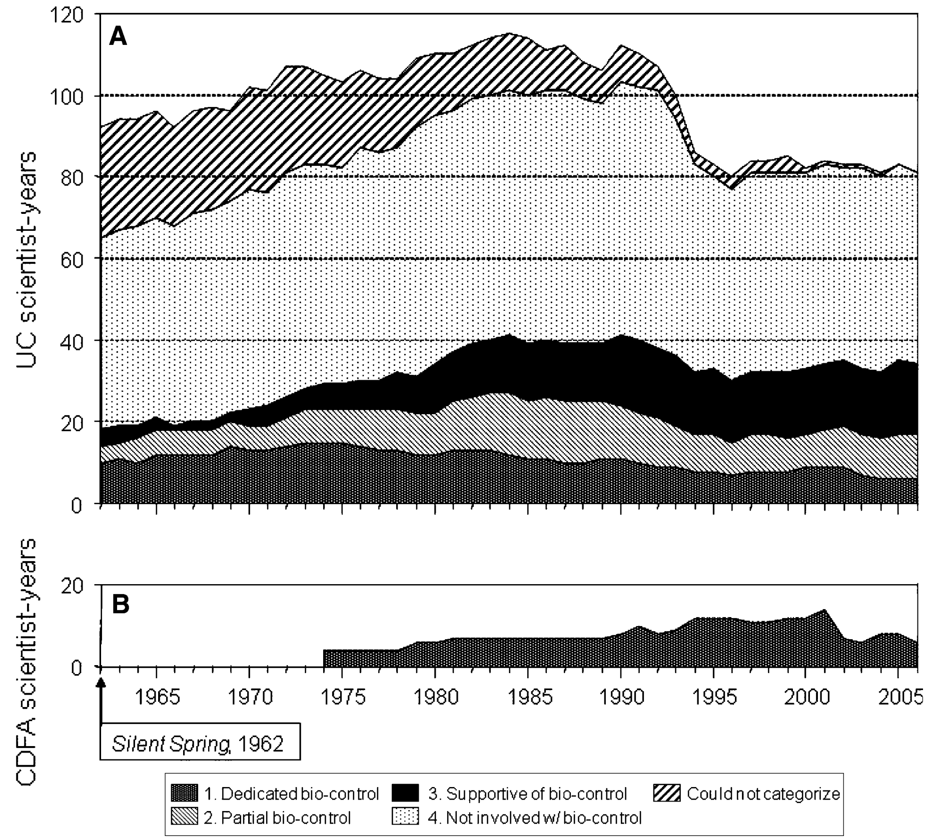


Fig. 1 Scientist-years categorized by researcher's relative investment in biological control (bio-control) research and/or extension from the publication of *Silent spring* in 1962 through 2006 for **A** the University of California (UC) Land Grant Universities and **B** California Department of Food and Agriculture (CDFA) Biological Control Program

Trends in institutional capacity, pest targets, and network configuration

The reduction in the number of "dedicated" bio-control researchers and their replacement with "partial" or "supportive" researchers must be viewed in terms of its impact on the practice of bio-control. The basic mission of individuals within the UC bio-control units of the 1960s and 1970s was problem-solving research. However, this applied mission did not reduce their academic accomplishments as many of the dedicated bio-control scientists managed complex scientific projects that included both basic and applied research. For example, 12 of 19 researchers published more than 100 scientific articles during their careers, with as many as 60% addressing some aspect of applied bio-control. The "multi-purpose" positions (code 2 and 3) in the 1980s and 1990s might be reflective of the declining capacity of the UC to conduct focused bio-control research. To be designated a scientist "supportive" of bio-control one only need conduct laboratory studies to publish a few scientific papers that have "biological control" in their titles. With increasing basic research studies and decreasing specialization in bio-control, few were trained in all subfields of the discipline necessary to implement a bio-control project.

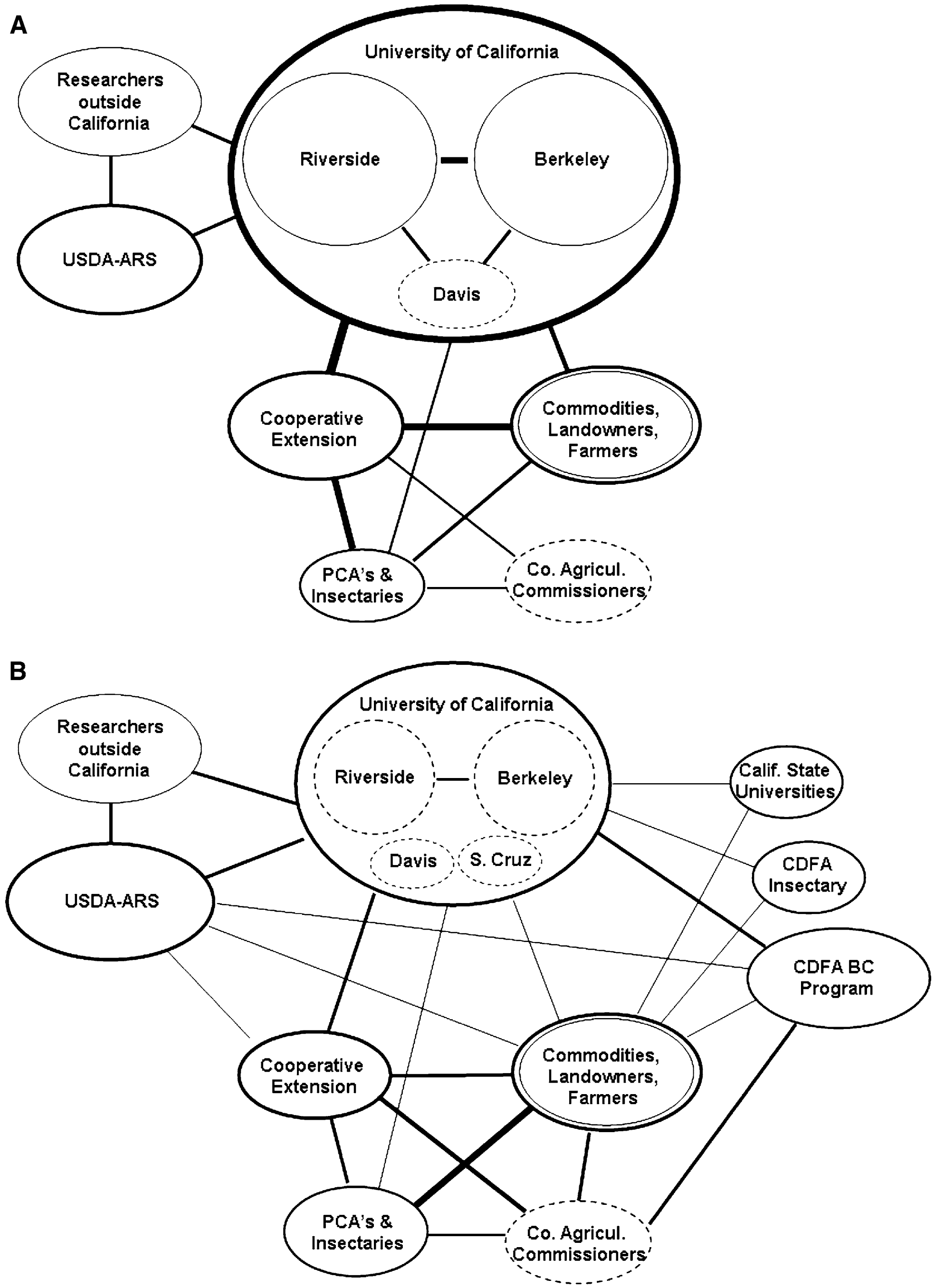
Along with a reduction in faculty positions in the 1980s and 1990s, there was a similar decrease in supporting personnel. In the 1960s and 1970s, each dedicated bio-control researcher had one or more staff research assistants (SRAs), and there were also career quarantine and insectary staff. These support personnel were professional entomologists and were key to the units' success; however, as faculty positions were reconfigured from dedicated bio-control to more multi-purpose positions, it was increasingly more difficult to justify support staff for an ever shrinking specialized field.

In 1974, CDFA re-established the Sacramento insectary, and four individuals were hired to mass produce and release natural enemies of the "skeletonweed" in cooperation with USDA researchers. CDFA's newly reinstated Biological Control Program grew considerably over the following 20 years until a 50% reduction in 2001 (Fig. 1B) trigged by a state budget contraction. Its mission is to help implement bio-control programs—a far more applied mission than that of the UC faculty—and its focus has chiefly been classical bio-control rather than other methodologies. Moreover, CDFA scientific personnel are free from most faculty responsibilities (e.g., teaching, publication pressure, committee service) and this difference from UC is considered, by some, to favor public interest research. Nevertheless, this program cannot function, under its current design, without cooperation from either the UC or USDA as the program depends upon the UC or USDA for quarantine space, specialized research, and program development. For example, UC and USDA researchers often conduct the needed studies on an exotic natural enemy's "non-target" impacts—in other words, will the predator imported to kill the pest insect also kill an unintended insect, such as a rare native moth (Fig. 2).

Interpreting the decline in capacity

How did the reduction in the numbers of California's bio-control researchers affect public interest research in bio-control? To assess the impact on public interest research we compared bio-control programs just prior to and then after the dismantling of the UC bio-control units. Analysis of California state quarantine records is beyond the scope of this study, and we focused on summary reports of

Fig. 2 Sociograms depicting the general structure of formal agencies involved with classical biological control of insect and mite pests in California during periods from **A** 1965 to 1975 and **B** 2000 to 2010. The relative size of each node suggests the relative number of personnel dedicated to bio-control research and extension, the relative size of the lines connecting each node suggest the level and importance of communication between each node. *Dashed lines* around each node suggest that either the agency supports but does not conduct bio-control (Commodities and County Agricultural Commissioners) or that the agency does not have a formal structure (e.g., the Riverside and Berkeley campuses post 1999)



classical bio-control projects: a summary of bio-control programs in the western US from 1964 to 1989 (Nechols et al. 1992); arthropod pests actively targeted from 1992 to 2006, based on interviews with UC personnel and Western Regional Project reports; and CDFA annual reports. To tabulate program impact, we used the coding system of De Bach and Schlinger (1964) of complete, substantial or partial control, which was assessed with the help of UC and CDFA scientists.

From the 1965 to 1989 summary of arthropod projects (Nechols et al. 1992) and a review of Quarantine efforts, 25 classical bio-control projects (based on targeted pests) were reported for insects or mites. Of these, there was nearly a 40% rate of complete or substantial control (Table 2). Only two projects were in cooperation with the USDA and one project with the newly formed CDFA Biological Control Program, as both of these other units dealt primarily with weed bio-control during this period. Of the 48 arthropod pests targeted by UC scientists from 1992 to 2006, 19 were reported to be under some degree of bio-control in 2007 (Table 2). For projects with unknown status, we assume no control. Complete or substantial control was provided in 14% of those arthropods targeted (this does not include projects coordinated with the CDFA program for implementation). Between 1993 and 2004, members of the CDFA Biological Control Program, along with cooperators at the UC or USDA Biological Control program, undertook 24 arthropod pest projects and reported complete or substantial control on 25% (Table 2). The category "no data" may indicate that the pest project is in the early stages of development or that the project has been suspended for lack of results or to prioritize other projects.

Table 2 Status as of 2007 of arthropod pests targeted by or proposed for UC bio-control efforts in 1992

Level of success[a]	UC Program		CDFA/UC/USDA
	1964–1989	1990–2006	1993–2004[b]
Complete control	5[c]	3	3
Substantial control	5[d]	4	3
Partial control	8	16	4
Unsuccessful	7	18	0
Deemed inappropriate target	0	0	4
No data	0	6	10
Total	25	48	24

[a] Projects and the level of success are self-reported summaries either from UC personnel in the USDA sponsored Western Regional Biological Control Project and personal interviews, or through the CDFA Biological Control Program Annual reports

[b] Prior to the "ash whitefly" project in the mid 1980s, the CDFA program was focused on rearing and releasing natural enemies for weed pests; no annual reports are available for work from 1974 through 1992. All of the CDFA projects were conducted in conjunction with either UC or USDA collaborators; for simplicity. To avoid duplication, we have not tabulated results for these projects under the UC program (1990–2006)

[c] One UC project was in cooperation with USDA personnel; one UC project was in cooperation with CDFA personnel

[d] Two UC projects were in cooperation with USDA personnel

This review is admittedly incomplete; nevertheless, it does provide important insights on changes to public interest research. First, the success rate in the early period (1965–1989) was near 40%, while the combined (UC and CDFA) success rate from latter period was 18%. Second, only 25 classical bio-control projects were reported from 1965 to 1989, while 72 were reported after 1992. We suggest that among the reasons for these trends are changes in SYs' support and research focus. The early period was marked by focused efforts against key pests. For example, bio-control efforts for the citrus pest "California red scale" spanned nearly 100 years. UC faculty members could devote their efforts to developing and fine tuning bio-control programs for this pest because they had long-term support through state-funded SRAs and industry research funds. Furthermore, promotional packages were not as dependent on publications, which may cause some projects to be dropped when solutions are not readily found. The increase in the number of bio-control projects attempted may result from scientists switching projects to follow available grant money, the increase in invasive species, and the increase in the number of multi-purpose faculty that enter into a bio-control project for the 4–5 year period of a graduate student.

The metrics used show a decline in the capacity of the two institutions studied (UC and CDFA) to conduct bio-control research and implement developed programs. In the UC system, the most important declines have been in the elimination of UC units dedicated to bio-control and the associated reduction in the number of overall SYs working in this field. The decline in dedicated public interest scientific positions at UC was not a development exclusive to California; for example, across the LGU system, plant breeders were replaced by molecular biologists (Busch 2005). We suggest that the decline in this public interest science correlates with a general decline in state support for agricultural research at LGUs. The fields of science have greatly expanded over the past few decades, primarily in molecular and biochemical arenas. Research outputs for many of these fields includes patentable products, procurement of multi-million dollar Federal grants and private gifts that have large University overheads, and publications in prestigious journals such as *Science, Nature*, and *PNAS*, which each bring accolades to the University and researchers. University administrators have directed their priorities and funding towards such academic pursuits over the past decades, even at LGUs where the stated mission of public interest science may be weakened as these other arenas increase. Thus the character of LGUs has changed as the incentives to pursue applied questions may not have the same monetary or academic rewards as basic research questions.

Here, we address a much broader set of challenges for agricultural science in the public interest than merely the field of bio-control, one of many subsets of public interest research. While Jennings' (1997) critique of UC leadership based on the "corruption theme" has some merit, this study presents a broader array of forces unraveling the social contract between LGUs and the public that funds them (McDowell 2001). This trend is particularly visible in California, where monetary, political, and environmental concerns have pushed agricultural interests further down the public agenda.

Reconfiguring networks of science and support

As a public interest science, bio-control requires support from three types of groups: participating scientists; farmers, ranchers, and landholders who directly benefit (e.g., growers, see Warner 2008); and those who advocate or supply public funding for bio-control research or implementation (Campbell 2001). Thus there is both a network of scientific practice and a network composed of clients and constituents. All participants interviewed for this project describe a steady decline in institutional capacity for bio-control here. We suggest that the bio-control units at Riverside and Berkeley provided more than laboratories for dedicated scientists. Their decline marked the loss of more than resources for individual researchers. The programs had dedicated personnel and stable, alternative spaces within university communities that supported scientists pursuing basic questions that had practical agricultural and environmental significance. As UC faculty numbers and support decreased, there was a compensatory increase in other organizational components in support of bio-control. The CDFA program assumed greater responsibility for the implementation of bio-control programs. Similarly, some county agricultural commissioners and commodity board research directors, who often operate as first-responders to invasive pests, created a regional conference to train their staff to better understand bio-control programs. Commodity board research directors have also expressed concern, ranging from moderate to serious, about the difficulties of securing scientists to conduct research in light of declining state support for UC (Warner 2007), and some have indicated that their organization would fund more bio-control research if researchers were available.

We suggest here that while the newly formed support and intra-agency communication is important, this cannot fully substitute for the past LGU bio-control units. Through their research, graduate students, and extension efforts, faculty at the dedicated LGU units provided coordination among different research arenas (e.g., insect ecology and pest control) as well as a network hub for pest control efforts that improved California agriculture, forestry, and landscape. We developed sociograms to illustrate how California's bio-control science networks have reconfigured during the past 35 years. Size and line width of each institution illustrates the relative importance of the node in the network, and line weight indicates relative importance of the relationship and communication between nodes for the overall functioning of the system. The dashed circles indicate the supportive role of county agricultural commissioners and commodity boards, but these agencies do not conduct classical bio-control. The sociograms show that in the 1960s and 1970s, the California's LGUs were the focal point, in some manner coordinating most classical bio-control activities on insect and mite pests. Campus-based faculty had strong ties to the field either directly to growers, the commodity boards that funded research, PCAs, and (most importantly) county-based cooperative extension agents. LGU faculty were the primary conduit for communication between California programs and researchers at the USDA or outside of California. The clientele (commodities, farmers, and landowners) worked primarily with the LGU faculty or their cooperating CE or PCA personnel for the application of novel bio-control programs. As described previously, the current size of the LGU is greatly diminished, and while other agencies have been formed (e.g., CDFA Biological Control Program), taken on new responsibilities (e.g., PCAs), or developed new research and extension links (e.g., USDA), there is an overall reduction in programmatic efficiency as the clientele now have many weaker links to novel bio-control programs. Essentially, there is a dispersion of tasks and no central leadership.

The second type of supportive network functioned external to these science institutions and gave voice to clients and public interest groups: conventional growers' organizations and Hightower-type activist groups. This network has expressed grave concern over the past decade about the direction of UC research more broadly straying from direct application to agriculture (Warner 2007). Nevertheless, the growers' networks in California have not been able to forestall continued reductions in agricultural research and extension. George McDowell (2001) argues that for LGU research and extension services to survive, they must be able to deliver a product that no other institution can and then cultivate political support from their client base. Instead, LGUs have cultivated commercial clients. LGU administrators have little incentive to reverse this trend, for in the absence of activist political pressure, other agricultural scientific work holds clearer promise of economic rewards (Glenna et al. 2007a).

Hightowerism in California found initial expression in networks that coordinated anti-pesticide, consumer health, pro-farm worker, and family farmer activism. The decline of bio-control here has taken place against the backdrop of the fraying of Hightower activism (Allen et al. 2003). Most sustainable and alternative agriculture groups here have abandoned direct advocacy efforts to shape the UC agricultural research agenda, finding more success elsewhere, often working with networks of farmers using alternative techniques and selling their produce through alternative markets.

Buttel (2005) observed that a marked decline in activist group attention to LGU research agendas took place as Hightowerism faded nationwide. This occurred as the overarching Hightower-type activism bifurcated into an agricultural sustainability/local food systems movement and a movement against transgenic crops (Buttel 2005). He argued that Hightowerism deployed ineffectual representational politics, and that these successor movements have more stable constituents. In his view, activist groups became frustrated with LGU intransigence and directed their attention elsewhere.

The decline of public interest agricultural science will likely continue unless a network of clients and constituents can provide a compelling rationale supported with a blend of public and private funds. Two possibilities suggest themselves: a network of local food systems/organic growers and the organic food industry; and a broad coalition of constituents concerned about invasive species: agricultural insects, weeds, aquatic and farm animal pests. A network such as one of these could give sufficient voice to support a public interest invasive species science program, one that could fulfill some of the functions of prior bio-control programs. If a broad network of citizens demanded this as a public interest science, crop bio-control could better reach its potential as an alternative to insecticides. Prior studies of California agriculture have demonstrated that environmental regulatory pressure can spur changes in farming practices, if appropriate scientific knowledge exists, or can be generated and exchanged within social networks (Warner 2007).

Conclusion

We have described the initiation of the first state bio-control program in the early 1890s, born from the spectacular success of the vedalia beetle, the transfer of this program to the UC in the 1920s, and its rise to international prominence after WW II to perhaps its zenith in the 1960 and 1970s. This study used scientometric methods to document the decline in institutional capacity for conducting bio-control research in California. This case illustrates the importance of investigating the dynamics within and between science institutions and the responses of the associated networks of support. It indicates the importance of investigating trends in SYs but also in the composition, structure, orientation, and institutional reward systems of scientific institutions. The evolution of the life sciences toward privatization unfolds concurrently with the increasing specialization and fragmentation of its sub-disciplines. Entomology has become more specialized. UC entomologists now work on single components of classical bio-control introduction projects, and they have fewer professional incentives for costly and unpredictable field exploration and post-release assessment. These forces function as a deterrent for scientists who might wish to undertake bio-control projects, but also to speak out publicly in favor of alternative scientific research priorities. In "the molecular age" (Buttel 2005), bio-control science is perceived by many university faculty and administrators as lacking the prestige and financial incentives of transgenic engineering.

This study reveals a broad array of extrinsic social forces that have impoverished public interest agricultural science institutions and weakened the two types of networks that could support public interest science criteria. To compensate for the suppression of two dedicated bio-control institutions, other participants in the scientific network have attempted to reconfigure supportive networks, with partial success. Both commodity grower groups and sustainable agriculture activist groups report frustration in their attempts to shape UC research agendas. Just as privatization pressures shape science, these forces have prompted a quasi-privatization of activist group discourses (Allen et al. 2003). The frustration of agricultural science research activists is an example of the broader erosion of citizen efforts to promote public interest science. This trend reflects the increasing intractability of research agendas more generally. Constituents or clients for bio-control still exist in California. Were they configured into coherent networks based on contemporary social aspirations and combined with sufficient regulatory pressure, public support for bio-control could translate into public interest science institutions.

This study suggests that the "corruption" narrative used by Hightower-type and other advocacy groups overly simplifies the changes that have taken place in scientific institutions. While a Golden Age of LGU research may have existed as a rhetorical strategy, the linear corruption narrative deployed by Hightower-type groups obscures the scope of social forces that have transformed LGU agricultural sciences (Buttel 2001). The decline of public interest science is very real, and the future of crop bio-control in California is dubious indeed. However, to represent the decline of a public interest science as the result of nefarious research administrators is but a caricature. The broad array of forces intrinsic and extrinsic to life sciences driving privatization suggests that any public interest science will require a deliberate intervention, i.e., advocacy guided by clear public interest criteria. Although there are few neutral forums for debating research priorities in America, advocacy for public interest science could make progress by presenting a compelling contrast between the notion of public good as the commercialization of discovery and technologies (as held by some university administrators, see Glenna et al. 2007a) and the unambiguous definition offered by Raffensperger et al. (1999).

Building upon prior scholarly concern with public interest agricultural science as a strategy to address sustainability goals, we extend this interest using quantitative metrics to assess the trajectory of one specific expression of such a concern. Our case study of public interest science can be contrasted with those of transgenic crop research and private interest science more generally. This study demonstrates that no single causal factor explains the decline of this science, and that the corruption narrative oversimplifies the diverse drivers of change in it. The increasing specialization of bio-control science; the transformation of the social organization of the life science work; the institutional reconfiguration of university research priorities; and the abandonment of this thematic area by civil society activist groups have all played a role.

Acknowledgments This research was supported by the California Department of Food and Agriculture and National Science Foundation award 0646658. This report would not have been possible without the active interest of many members of these institutions helping us to understand the history and organization of biological control in California. John Steggall, Michael Pitcairn, Charles Pickett, Mark Hoddle, Daniel Sullivan, and David Headrick provided important insights on these data. Laurie Allen at UC Riverside, Louise Meyer Ozawa at UC Berkeley and Brenda Wing at UC Davis were particularly helpful in tracking down data about biological control scientists.

References

Allen, P., M. FitzSimmons, M. Goodman, and K.D. Warner. 2003. Shifting plates in the agrifood landscape: The tectonics of alternative agrifood initiatives in California. *Journal of Rural Studies* 19(1): 61–75.

Altieri, M.A. 2002. Agroecology: The science of natural resource management for poor farmers in marginal environments. *Agriculture, Ecosystems & Environment* 93(1/3): 1–24.

Altieri, M.A. 1984. Pest-management technologies for peasants: A farming systems approach. *Crop Protection* 3(1): 87–94.

Andow, D.A. 1991. Vegetational diversity and arthropod population response. *Annual Review of Entomology* 36: 561–586.

Baker, B. 1988. Pest control in the public interest: Crop protection in California. *UCLA Journal of Environmental Law* 8(1): 31–71.

Busch, L. 2005. Commentary on: Ever since Hightower: The politics of agricultural research in the molecular age. *Agriculture and Human Values* 22: 285–288.

Busch, L., and W.B. Lacy. 1983. *Science, agriculture, and the politics of research*. Boulder, CO: Westview.

Buttel, F. 2001. Land-grant/industry relationships and the institutional relationships of technological innovation in agriculture. In *Knowledge generation and technological change*, ed. S. Wolf, and D. Zilberman, 151–176. Boston, MA: Kluwer.

Buttel, F. 2005. Ever since Hightower: The politics of agricultural research activism in the molecular age. *Agriculture and Human Values* 22(3): 275–283.

Buttel, F., O. Larson, and G. Gillespie. 1990. *The sociology of agriculture*: Greenwood.

Callon, M., J. Law, and A. Rip. 1986. Quantitative scientometrics. In *Mapping the dynamics of science and technology*, ed. M. Callon, J. Law, and A. Rip, 103–123. London: The MacMillan Press.

Caltagirone, L.E. 1981. Landmark examples in classical biological control. *Annual Review of Entomology* 26: 213–232.

Caltagirone, L.E., and R.L. Doutt. 1989. The history of the vedalia beetle importation to California and its impact on the development of biological control. *Annual Review of Entomology* 34: 1–16.

Campbell, D. 2001. Conviction seeking efficacy: Sustainable agriculture and the politics of co-optation. *Agriculture and Human Values* 18: 353–363.

Carson, R. 1962. *Silent spring*. Boston, MA: Houghton Mifflin.

Compere, H. 1969. *Changing trends and objectives in biological control. Proceedings, 1st International Citrus Symposium, 755–764*. Riverside, CA: University of California, Riverside.

Croissant, J., and S. Restivo. 2001. *Degrees of compromise: Industrial interests and academic values*. Albany, NY: State University of New York Press.

Dahlberg, K.A., and M. Koc. 1999. The restructuring of food systems: Trends, research, and policy issues. *Agriculture and Human Values* 16(2): 109–116.

De Bach, P., and E.I. Schlinger. 1964. *Biological control of insect pests and weeds*. New York: Reinhold Publishing Company.

Delborne, J. 2008. Transgenes and transgressions: Scientific dissent as heterogenous practice. *Social Studies of Science* 38(4): 509–541.

Doutt, R.L. 1964. The historical development of biological control. In *Biological control of insect pests and weeds*, ed. P. Debach, and E.I. Schlinger, 21–42. New York: Reinhold Publishing Corporations.

Ehler, L.E. 2005. Integrated pest management: A national goal? *Issues in Science and Technology* 22: 25–26.

Eilenberg, J., and H.M.T. Hokkanen. 2006. *An ecological and societal approach to biological control*. Dordrecht, The Netherlands: Springer.

Friedland, W.H. 1991. “Engineering” social change in agriculture. *University of Dayton Review* 21(1): 25–42.

Glenna, L., W.B. Lacy, R. Welsh, and D. Biscotti. 2007a. University administrators, agricultural biotechnology, and academic capitalism: Defining the public good to promote university-industry relationships. *The Sociological Quarterly* 48(1): 141–163.

Glenna, L., R. Welsh, W.B. Lacy, and D. Biscotti. 2007b. Industry perceptions of university-industry relationships related to agricultural biotechnology research. *Rural Sociology* 72(4): 608–631.

Greathead, D.J., and P. Neuenschwander. 2003. Historical overview of biological control in Africa. *Biological control in IPM systems in Africa* 1–26.

Gurr, G.M., S.D. Wratten, and M.A. Altieri. 2003. Ecological engineering for enhanced pest management: Towards a rigorous science. In *Ecological engineering for pest management: Advances in habitat manipulation for arthropods*, ed. G.M.

Gurr, S.D. Wratten, and M.A. Altieri, 219–225. Collingwood, Australia: CSIRO Publishing.
Gurr, G.M., N.D. Barlow, J. Memmott, S.D. Wratten, and D.J. Greathead. 2000. A history of methodological, theoretical, and empirical approaches to biological control. In *Biological control: Measures of success*, ed. G.M. Gurr, and S.D. Wratten, 3–37. Dordrecht, Netherlands: Kluwer.
Hadwiger, D.F. 1982. *The politics of agricultural research*. Lincoln, NB: University of Nebraska Press.
Hightower, J. 1973. *Hard tomatoes, hard times*. Cambridge, MA: Schenkman Publishing Company.
Huffaker, C.B., and P.S. Messenger. 1976. *Theory and practice of biological control*. New York, NY: Academic Press.
Jennings, B.H. 1997. The killing fields: Science and politics at Berkeley, California, USA. *Agriculture and Human Values* 14: 259–271.
Kleinman, D.L. 2003. *Impure cultures: University biology and the world of commerce*. Madison, WI: University of Wisconsin Press.
Kloppenburg, J.R. 2004. *First the seed: The political economy of plant biotechnology*. Madison, WI: University of Wisconsin Press.
Krimsky, S. 2003. *Science in the private interest: Has the lure of profits corrupted biomedical research?*. Lanham, MD: Rowman & Littlefield.
Lacy, W., and L. Glenna. 2006. Democratizing science in an era of expert and private knowledge. *International Journal of Technology, Knowledge and Society* 1(3): 37–45.
Leydesdorff, L. 2001. *The challenge of scientometrics: The development, measurement, and self-organization of scientific communications*. Boca Raton, FL: Universal Publishers.
Lounsburyi, C.P. 1940. The pioneering period of economic entomology in South Africa. *Journal of the Entomological Society of South Africa* 3: 9–29.
Luck, R.F., and D.L. Dahlsten. 1975. Natural decline of pine needle scale (*Chionaspis pinfoliae* (Fitch)), outbreak at South Lake Tahoe, California following cessation of adult mosquito control with malathion. *Ecology* 56: 893–904.
McDowell, G. 2001. *Land-grant universities and extension into the 21st century: Renegotiating or abandoning a social contract*. Ames, IA: Iowa State University Press.
Nechols, J.R., L.A. Andres, J.W. Beardsley, R.D. Goeden, and C.G. Jackson. 1992. *Biological control in the Western United States: Accomplishments and benefits of regional research project W-84, 1964–1989*. Oakland, CA: University of California Division of Agriculture and Natural Resources Publication 3361.
Palladino, P. 1996. *Entomology, ecology, and agriculture: The making of scientific careers in North America, 1885–1985*. Amsterdam: Harwood Academic Publishers.
Perkins, J.H. 1982. *Insects, experts, and the insecticide crisis*. New York: Plenum Press.
Perkins, J.H., and R. Garcia. 1999. Social and economic factors affecting research and implementation of biological control. In *Handbook of biological control*, ed. T. Bellows, and T. Fisher, 993–1104. San Diego, CA: Academic Press.
Raffensperger, C., S. Peters, F. Kirschenmann, T. Schettler, K. Barrett, M. Hendrickson, D. Jackson, R. Voland, K. Leval, and D. Butcher. 1999. *Defining public interest research*. http://www.sehn.org/defpirpaper.html. Accessed 12 April 2010.
Ridgway, R.L., and M.N. Inscoe. 1998. Mass-reared natural enemies for pest control: Trends and challenges. In *Mass-reared natural enemies: Application, regulation, needs*, ed. R.L. Ridgway, M.P. Hoffman, M.N. Inscoe, and C.S. Glenister, 1–26. Lanham, MD: Entomological Society of America.
Rudy, A.P., D. Coppin, J. Konefal, B.T. Shaw, T. Ten Eyck, C. Harris, and L. Busch. 2007. *Universities in the age of corporate science: The UC Berkeley-Novartis controversy*. Philadelphia: Temple University Press.
Sawyer, R.C. 1996. *To make a spotless orange: Biological control in California*. Ames IA: Iowa State University Press.
Sawyer, R.C. 1990. Monopolizing the insect trade: Biological control in the USDA 1888–1951. *Agricultural History* 64(2): 271–285.
Simmonds, F.J., J.M. Franz, and R.I. Sailer. 1976. History of biological control. In *Theory and practice of biological control*, ed. C.B. Huffaker, and P.S. Messenger, 17–39. New York: Academic Press.
Smith, H.S. 1919. On some phases of insect control by the biological method. *Journal of Economic Entomology* 12: 1–13.
Stoll, S. 1998. *The fruits of natural advantage: Making the industrial countryside in California*. Berkeley, CA: University of California Press.
Stoll, S. 1995. Insects and institutions: University science and the fruit business in California. *Agricultural History* 69(2): 216–239.
Turnbull, A.L., and D.A. Chant. 1961. Practice and theory of biological control of insects in Canada. *Canadian Journal of Zoology* 39(5): 697–753.
van den Bosch, R. 1978. *The pesticide conspiracy*. Berkeley, CA: University of California Press.
van den Bosch, R., P.S. Messenger, and A.P. Gutierrez. 1982. *An introduction to biological control*. New York: Plenum Press.
Van Driesche, R.G., and D.N. Ferro. 1990. Will the benefits of classical biological control be lost in the "biotechnology stampede"? *American Journal of Alternative Agriculture* 2(50): 50.
Viggiani, G. 2000. The role of parasitic Hymenoptera in integrated pest management in fruit orchards. *Crop Protection* 19(8–10): 665–668.
Warner, K.D. 2008. Agroecology as participatory science: Emerging alternatives to technology transfer extension practice. *Science, Technology & Human Values* 33(6): 754–777.
Warner, K.D. 2007. *Agroecology in action: Extending alternative agriculture through social networks*. Cambridge, MA: MIT Press.
Warner, K.D., and C. Getz. 2007. A socio-economic analysis of the North American commercial natural enemy industry and implications for augmentative biological control. *Biological Control* 45: 1–10.
Warner, K.D., C. Getz, S. Maurano, and K. Powers. 2009. An analysis of historical trends in classical biological control of arthropods suggests need for a new centralized database in the USA. *Biocontrol Science and Technology* 45: 1–10.
Wilson, F. 1960. A review of the biological control of insects and weeds in Australia and Australian New Guinea. *Commonwealth Institute of Biological Control Technology and Communications* 1: 1–102.

Author Biographies

Keith D. Warner OFM, PhD, is a Franciscan Friar on the faculty of Santa Clara University, where he is also assistant director of education for the Center for Science, Technology & Society. He has an MA in Franciscan Spirituality (Franciscan School of Theology in Berkeley), and a doctorate in Environmental Studies (University of California—Santa Cruz). His doctoral dissertation deployed STS methods to investigate how social networks extended ecologically informed farming systems. His current research addresses the evolution of religious environmental ethics, and how ethics and values shape classical biological control practice and policy.

Kent M. Daane PhD, is a Cooperative Extension Specialist at the University of California, Berkeley. He received his PhD in Entomology in 1988 and has since worked on the development arthropod control programs that emphasize biological controls, insect ecology, and manipulation of the crop system to lower pest or support natural enemy populations. His current research includes invasive insect pests in vineyards, olives, and almonds.

Christina M. Getz PhD, is an Associate Cooperative Extension Specialist in the Department of Environmental Science, Policy, and Management at the University of California, Berkeley. A sociologist by training, she conducts applied research and outreach focused substantively on social justice in sustainable agriculture, food security and sustainability in agriculture and natural resource systems, and participatory capacity building within cooperative extension. Her research currently focuses on social justice issues in the organic agriculture and small-farm sectors.

Stephen P. Maurano currently works in the Urban Forestry field in the San Francisco Bay Area. Previously he worked as an agricultural extension agent with the US Peace Corps, Paraguay, providing technical support to small-scale producers in areas including erosion mitigation, IPM, and organic pest control. He has BS in Biology and in Environmental Science from Santa Clara University.

Sandra Calderon completed a BS in Environmental Science at Santa Clara University.

Kathleen A. Powers completed a BS in Biology with an emphasis on Evolution and Ecology at Santa Clara University. She has conducted research into animal behavior, ecology and evolution, biocontrol institutions, and public health in Latin America. She is currently applying to medical schools.