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Synthesis:

Can we make locust and grasshopper management sustainable?

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Abstract

Scale is the fundamental conceptual problem in assessing the sustainability or value of controlling grasshoppers or locusts. Using case studies from North America (United States: Wyoming), Africa (Eritrea), and Asia (Russia: Irkutsk), we analyzed the viability of control programs. There are at least four dimensions to acridid pest management. At the **geopolitical scale**, all three cases reveal that although the greatest cost/risk of acridid outbreaks accrues locally, distant governments play a primary role despite recent, undirected trends toward decentralization. Examination of the **social scale** reveals that in all three cases, the individual farm/ranch is the fundamental unit of concern, but these units place high value on preventing acridid infestations from spreading to neighboring lands. None of the systems appear to be driven by the agrochemical industry; rather, the motive force is food security (Eritrea), food quality (Wyoming), or both (Irkutsk). With respect to the **interest scale**, in all three systems agriculturalists have nothing to gain and much to lose from acridid outbreaks, as compared to the general public (no gains, modest losses), agrochemical industries (low gains, no losses), and governments (low gains, modest losses). In terms of the **temporal scale**, extremely rapid (and localized) losses and short-term (annual) productivity define the situation for farmers/ranchers, while governments exhibit far slower and longer-term responses and perspectives. From these findings, the keys and obstacles to sustainable acridid pest management are discussed.

Key words

Scale, spatiotemporal, values, decentralization, grasshoppers, locusts, management

Simon Levin (1992) noted that "[scale is] the fundamental conceptual problem in ecology, if not in all of science". In the physical, biological, and sociopolitical realms, what we believe to be opposing theories often are a matter of equally valid concepts being advanced at different scales. As such, when people's perceptions conflict, the tension may be a function of mismatched scales, rather than opposing philosophies.

The value and ultimate sustainability of controlling grasshopper and locust outbreaks is a matter of continuing and intense debate (Office of Technology Assessment [OTA] 1990). Sustainability is the potential for a pest management system to persist indefinitely. This definition does not disallow adaptation and change in the system, as long as these dynamics are made explicitly possible by the program. In the simplest terms, to be sustainable a pest management system must be environmentally rational (*e.g.*, it cannot erode the ecological processes that allow the commodity of concern to be produced), culturally viable (*e.g.*, it cannot require practices that would offend the sensibilities of the people), politically tenable (*e.g.*, it cannot be legally or socially prohibited), and economically profitable (*e.g.*, it can not cost more than the perceived benefits, however these may be interpreted).

Various economic analyses have been undertaken to assess the monetary returns of locust management strategies (Bullen 1970, Krall 1995, Krall & Herok 1997, Food and Agriculture Organization of the United Nations [FAO] 1998). As useful as these attempts have been in clarifying particular aspects of grasshopper and locust control, they have been fairly criticized for ignoring constraints, utilizing poor data, oversimplifying structural elements, and externalizing both costs and benefits. Although not explicitly recognized previously, most of the conflicts of interpretation appear to arise from mismatched scales, in which the analyst assumes a particular scope of study usually dictated by the available data, tractability of the model, or cultural bias, and the critic presumes a different perspective from which the analysis becomes invalid. For example, in critiquing the 1998 FAO study on the economics and policies pertaining to desert locust management, workshop participants raised various objections concerning whether the analysis should have included the perspective of nomads, the value of food security, the costs of environmental damage, the sociological constraints of different countries, and the humanitarian benefits of pest management (FAO 1998).

Not only are there important nonrational externalities that defy economic transformation by contingent valuation (*e.g.*, the constraints of cultural and amenity values), but the agents in the system are engaged in complex conversions of inputs and outputs (*e.g.*, governments may exchange materials for political good will and the public may exchange money for a sense of moral righteousness). Add to these elements the imperfect flow of information and the unequal distribution of power, and the failure of standard economic

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analyses is assured.

There are at least four dimensions of scale for consideration when defining — and solving — the conflicts arising from efforts to determine whether grasshopper and locust control programs are sustainable. These scales include: geopolitics, human purposes, social interests, and time. To investigate how these scales affect the sustainability of acridid pest management systems we have analyzed arguably representative cases from three different regions: Eritrea, Irkutsk (Russia), and Wyoming (USA) (Fig.1). Although these regions represent different political levels, they encompass similar areas of land (121,320 km^2 for Eritrea, 253,600 km^2 for Wyoming [of which about one-half is susceptible to acridid outbreaks], and 767,900 km^2 for Irkutsk [of which about one-fourth is suitable habitat for acridids) for consistent comparison at this basic level.

The primary purpose of this analysis is to describe and synthesize issues among different cases in a global context and to develop a universal framework for discussing complexities of acridid management systems. A "comparative" approach allows a determination as to whether an issue is generally relevant and fundamentally important to acridid pest management, or whether it is particular in its application, having local implications that cannot be readily generalized. The cases span a wide spectrum of acridid pest situations, representing: tropical and temperate habitats; grasshoppers, mixed populations, and locusts; wealthy, developing, and impoverished conditions; and African, Asian, and North American concerns. These cases represent situations about which the authors have extensive, first-hand experience and knowledge. Although a larger number of cases might be valuable, even the concise description of three systems required relatively lengthy treatment.

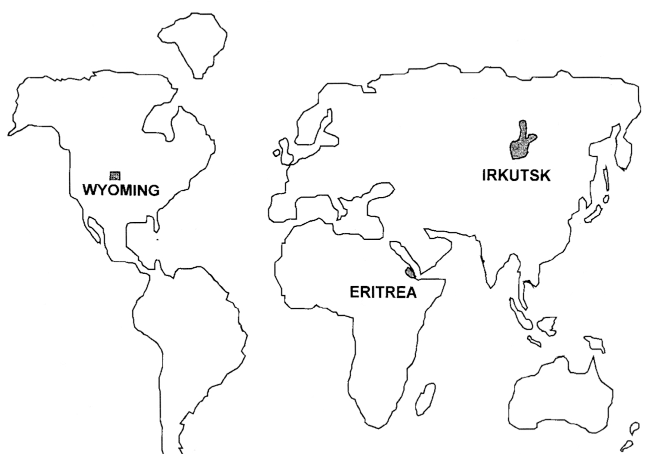

Fig.1. World map showing the locations and approximate sizes of the lands that constitute the case studies of this analysis.

Geopolitical Scale

The answer to whether an acridid outbreak is worth controlling can vary depending on the spatial scale at which it is assessed. Although the most appropriate units of space might be ecological, because our question explicitly invokes the presence of humans as both the agents of control and assessing value, political boundaries are likely to provide the most meaningful units for analysis. These units include individual landholdings (farms or ranches), rural communities (villages, towns), local governments (counties, districts, sectors, rayons), regional governments (states, provinces, zones, oblasts), nations, and international or global collectives.

Eritrea.— Desert locusts, *Schistocerca gregaria* (Forskål), threaten agriculture when nymphal bands or adult swarms invade cultivated or pasture lands. Because swarms can be comprised of millions of individuals and can consume nearly every kind of green vegetation (Steedman 1988), the gregarious phase has the potential to cause complete crop losses at the local scale within hours.

At the individual agriculturalist's level, locust invasion can mean complete crop loss unless the season's crops can be replanted. Economic effects can be profound for both subsistence farmers and commercial growers. The intermittence of desert locust infestations does not detract from the immediate severity of damage when feeding insects are present.

In terms of the rural community, Eritrea's general public, most of whom are themselves farmers or closely related to farmers, expect that their government will conduct control operations, proactively if possible (Showler 1995a,b, 1997). Farmers and nomads also participate in government-coordinated survey and control campaigns, usually as scouts or assistants.

Local, zonal, and national governments participate in desert locust survey and control. Many of the surveys are conducted with agents from two or more government strata, and control is primarily financed from national and zonal budgets. During plagues, however, the costs of equipment, supplies, training, survey and control can exceed the capacity of the Ministry of Agriculture. During the 1992-1994 desert locust outbreak (Showler 1995b), which began, in part, on Eritrea's Red Sea coastal plains, emergency donor assistance was provided to Eritrea. When Eritrea was invaded by African migratory locust, *Locusta migratoria migratorioides* (Reiche & Fairmaire) in 1995, limited donor contributions in cash and in kind were used to control them before they reached coastal breeding areas. However, during the outbreak of 1997-1998 (Showler 2001a), Eritrea detected hopper bands along the coastal plains and eliminated them before swarms developed, without emergency donor assistance.

On a regional (international) scale, allowing desert locust populations to cross national borders can degrade relations among neighboring countries. Since gaining independence in 1992, Eritrea has had armed conflicts with Ethiopia and Yemen, and it has come perilously close to military engagements with Djibouti and Sudan. In the last decade, most countries in the Red Sea region have been involved in wars which affected locust control capabilities (Showler 2001b). Prior to this time, Eritrea's 30-year war for independence from Ethiopia impeded control operations during the 1986-1989 plague (Showler & Potter 1991).

On a global scale, some international aid agencies are

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sometimes uncertain as to which bureau is responsible for locust plagues, or if locust control warrants a place in the portfolio of these agencies. Donor agencies often categorized the 1986-1989 plague as a disaster because material assistance had to be supplied at short notice using emergency procurement mechanisms in support of a reactive campaign (Showler 1997). When the plague had ended as a result of climatic changes (Showler & Potter 1991), the locust issue was moved into development portfolios with the expectation that plagues can be prevented by strengthening national and regional capabilities. During recession years, agency priorities tend to shift to more imminent exigencies or politically advantageous activities. The rapidity with which the locust issue becomes sidelined reflects the ephemeral focus of the international development community following major outbreaks and plagues. For example, the desert locust component of the Food and Agriculture Organization (FAO) of the United Nations' Emergency Prevention System (EMPRES) was mostly staffed by the end of 1997, but aid agency support began to diminish just 1 y after launching what was to be a 12-year program (FAO/EMPRES 1998).

Governments wealthy enough to fund economic assessments tend to adopt a macro-economic perspective, overlooking subsistence farmers and pastoralists, who are the predominant agriculturalists in Eritrea, but cannot be meaningfully valued using monetary units. By the end of the 1986-1989 desert locust campaign, the international community used the term "donor fatigue" when describing aid agencies' declining interest. An FAO (1998) report indicated that desert locust control might not be cost effective but deferred a definitive analysis to later studies. However, Eritrea is a unique desert locust-affected country in that it has largely shunned foreign aid in favor of self reliance, and corruption has been methodically extirpated; hence, donors look favorably on requests for assistance. With another major plague, the funding cycle may well be renewed with a level of international assistance similar to the $310 million provided to desert locust-affected countries in 1986-1989 (Showler & Potter 1991).

There also exist subtle conflicts of interest that impeded early intervention strategies. Some regional locust management organizations have been suspected of responding slowly so that outbreaks might expand and generate more income from contract services. Multilateral and bilateral programs continue to receive federal tax-based support for staffs that sometimes exaggerate the locust situation to assure job security or to increase career-enhancing supervisory responsibilities. As in war, people profit and profiteer from direct and overhead costs associated with large desert locust campaigns and the development projects they spawn.

Irkutsk.— Grasshopper control in Russia represents a part of the general plant protection activities implemented by the governmental organization, the Federal Plant Protection Service (FPPS) of the Ministry of Agriculture of the Russian Federation. In Irkutsk Oblast, the regional organ of the FPPS is the Oblast Plant Protection Station (PPS). The PPS specialists conduct grasshopper monitoring, which includes three successive surveys during the growing season. According to the official guidelines, the threshold for chemical intervention against grasshoppers was 1-3 grasshoppers per m^2 (Tsyplenkov 1979). However, in practice, chemical treatments are usually applied only if grasshopper densities exceeded 10-15 per m^2. These practices are reflected in the new official guidelines which recommend treating grasshopper populations if the densities are >10 individuals per m^2 (Naumovich *et al.* 2000).

Until the collapse of the former Soviet Union in 1991, all grasshopper monitoring and control activities (in case of an outbreak) were financed by the federal government. The insecticides were provided through the centralized budget. The PPS specialists organized and supervised the control operations which were executed by the treatment teams from local agricultural cooperatives. Because grasshopper control was a routine element of pest management together with other related activities, the costs of grasshopper treatments were absorbed by the cooperatives. However, this system worked without additional spending only when grasshopper numbers were relatively low. Such a situation persisted in Irkutsk during several decades of the second half of the 20th century when annual grasshopper control operations did not exceed 10-20 thousand ha. The collapse of the Soviet Union coincided with an upsurge of grasshopper populations caused by several consecutive drought years and a general decline of agriculture in the transition period. Abandonment of large areas of previously cultivated land resulted in the creation of fallow habitats suitable for the buildup of pest grasshopper populations (*e.g.*, *Aeropus sibiricus* (L.)).

The combination of these ecological and political factors resulted in a grasshopper outbreak in 1992-1994. In 1994, 380,000 ha were surveyed and 325,700 ha were treated in the Irkutsk Oblast (Latchininsky 1997). This was larger than the largest area ever treated throughout Russia in the previous 70 years. During this outbreak, insecticides and aerial treatments were funded by the federal government, which hired 36 aircraft. Ground treatment teams were funded from local resources. The primary concern was to prevent crop losses, but >500,000 ha of grain crops were damaged by grasshoppers in 1994.

After several years of relatively low grasshopper densities, another grasshopper outbreak was reported in 2000 and about 100,000 ha were treated. It was the second outbreak in 10 years although there were no significant outbreaks in the previous 60 years. During the 2000 outbreak, only insecticides were procured by the federal government. All treatment costs were shared by the local (Oblast) government and agricultural cooperatives. The role of the PPS was mostly advisory. Thus, there is a pronounced tendency of decentralization of grasshopper control in Russia. Still, grasshopper outbreaks are considered as being federal emergencies, and heavily infested areas can qualify for federal disaster relief assistance for funding control programs.

It is noteworthy that the land ownership legislation is still not adopted in Russia (currently, the relevant bill is under consideration by the Russian parliament). Because of that, the proportion of private agricultural producers is still low in the Irkutsk Oblast. Private farms currently use <10%

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of the agricultural lands. Even then they technically do not own the land but use it under a long term lease. Grasshopper control is not subsidized on such lands, and private producers have to absorb insecticide and application costs.

Wyoming.— The geopolitical scale of grasshopper control in Wyoming and the rest of the western USA changed dramatically in the last decade. Following a major outbreak involving several species in 1985-1986 which resulted in >8 million ha being treated, the US Department of Agriculture (USDA) came under intense scrutiny. The USDA provided subsidies for rangeland grasshopper control, supporting 100% of the costs on federal lands leased to private ranchers for livestock grazing, 50% on state lands also leased to ranchers, and 33% on private land. The policy of the USDA during the cost-share program was to treat areas of no less than 4,000 ha, with the largest single treatment block being 2.5 million ha. Such programs necessarily involved a complex mixture of land ownerships, typically including federal, state, and private land owners. The immense scope of acridid control in the 1980s combined with the downsizing of the federal government, led to a 1997 decision to withdraw USDA support (logistical and financial) from rangeland grasshopper control programs (Husnik 1995), with the exception of those limited areas in which grasshopper infestations on federal lands threaten adjacent, private croplands (private and state rangelands are apparently excluded from this "good neighbor" provision). In theory, other federal land management agencies responsible for vast tracts of rangeland in the western US that are leased to ranchers could provide the USDA with funding to implement survey and control programs, but other concerns have taken higher priority. As such, with the termination of the subsidy program, the geopolitical scale of grasshopper management shifted from a national or regional (interstate) perspective to individual ranches.

As private producers were forced to absorb all of the costs of control, they appealed to county-level weed and pest districts for survey and treatment assistance. In turn, these districts sought financial assistance from the state government. Although a new infrastructure is still developing, it appears likely that acridid surveys will be organized and supported at the inter-county level, with the state providing financial assistance, and counties in grasshopper outbreak areas, unifying their survey practices and reporting under a common set of standard methods developed at the University of Wyoming (Legg & Lockwood 2001).

With respect to treatments, a few counties provide a small subsidy using funds derived from taxes on agricultural lands, as local weed and pest districts have the authority to levy limited taxes to support their efforts. However, the majority of the decisions and treatments are made at the level of the individual ranch or sets of ranches. Compared to the control programs prior to 1995, recent treatments have been smaller in scale (300 to 2,000 ha) and less frequent. Ranchers appear to be more tolerant of moderate grasshopper densities and less likely to treat when conditions are ambiguous with respect to the likelihood of economic returns (Branting *et al.* 1997). Perhaps most importantly, these treatments have exploited the practice of reduced agent-area treatments (RAATs); (Lockwood & Schell 1997, Lockwood *et al.* 2000a), which have reduced the application costs and the amount of insecticides applied by 66-75%. These methods were developed in Wyoming and have been rapidly adopted across the western US, suggesting that agriculturalists are capable of breaking with tradition (*i.e.*, blanket applications of insecticides at high rates) and adopting increasingly rational strategies when conditions demand such changes. Although RAATs are emerging as the standard approach to rangeland grasshopper management nationally, it is relevant to note that the funding for the initial studies was provided by two weed and pest districts in Wyoming, who sought a method to reduce treatment costs for constituent ranchers.

Synthesis.— A number of geopolitical themes emerge from the particular pest management systems that have developed in Eritrea, Irkutsk and Wyoming. First, all three geopolitical units can be described as having developed acridid pest management systems in which there was a central role of, and dependence on, distant governments. In the case of Eritrea, the distant governments are those of donor nations as well as the national government. However, even in Wyoming and Irkutsk, where foreign assistance has not been a consideration, the role of federal or national governments has been operationally and functionally that of an external government, having political interests that are substantially different from the rural (agricultural) concerns of those whose lands are infested with grasshoppers or locusts.

All three cases exhibit a similar dynamic with respect to the role of government. In each instance there is a general, but largely undirected, trend toward decentralization. In Eritrea, this is manifest by the decline in external (donor) support during recessions, which parallels the withdrawal of external (federal) support in Wyoming. Even in Russia, greater responsibilities for acridid pest management have accrued at the Oblast level, but the national government remains an important element of the system. All three systems appear to be actively struggling with reinventing approaches to acridid pest management with the aim of increasing responsibilities at the local level.

Across the three systems the greatest cost or risk of acridid outbreaks accrues at the local scale — the individual farm or ranch — and the most significant political risk is seen at the lowest organizational level. Although failing to suppress an acridid outbreak can have political costs from the local to the international level, the toll is relatively short-lived and minor in comparison to many other crises. As such, the concern over acridid infestations is inversely proportional to the geopolitical scale, with the most expansive (national and international) agencies having the least compelling risks from failing to respond adequately.

Finally, localization of management appears likely to generate less intensive pest management interventions, thereby increasing the likelihood of conflicts across geopolitical borders. In Africa, this tension is manifest between neighboring countries as a consequence of invasions by uncontrolled locust swarms. In Irkutsk and Wyoming, the scale of the border conflicts is more local, potentially occur-

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ring between individual landholders or local political units (rayons in Irkutsk or counties in Wyoming).

Social Scale

People assemble into broad, overlapping but nonidentical spheres of concern pertaining to acridid pest management. These sociological units may reflect the spatial scale to some extent, but they are not constrained with respect to space. These spheres of concern can be stereotyped, understanding that any individual, agency, organization, or company may be included in multiple perspectives to varying degrees. The most relevant sociological groupings include: producers (agriculturalists directly affected by acridid infestations and control programs), consumers (people who consume the food produced by agriculture and indirectly benefit from the derivative value of agricultural markets), business (people who depend on the producers to consume their goods and services or who serve as intermediaries in processing and marketing agricultural products), and government (people who provide the legal and regulatory infrastructure and services to producers, consumers, and business).

Eritrea.— In Eritrea, there is a complex mixture of social scales (and corresponding purposes) across which locust control is important, including: 1) farmer (to eliminate swarms before they can arrive in cultivated fields), 2) local official (to keep constituents and superiors from getting angry and removing the official from office, to protect the local market upon which the farmer depends, to protect the agrarian family or personal farming interests, and to serve the newly independent country [in Eritrea, many agricultural officers were in the Eritrean People's Liberation Front {EPLF}and view their job as a patriotic duty]), 3) district manager (to sustain agricultural production in the manager's region and to honor civic duty as a veteran of the EPLF), 4) Minister of Agriculture (to improve agricultural production in Eritrea and serve the nation [the Eritrean Minister of Agriculture is, as of this writing, an ex-EPLF guerrilla, as is the Minister of Natural Resources and the Environment]), 5) foreign embassy official (to provide an opportunity to present the image of international friendship through delivery of insecticides and equipment, often produced by the mother country's corporations, and to maintain political stability within the host country), 6) international relief worker (to avert factors that might contribute to famine), 7) international development employee (to reduce or prevent desert locust plagues and to justify the continuance of programs that assure the development employee's job security), and 8) U.S. taxpaying public (to sustain domestic economic prosperity and to help needy peoples, although most of the public is unaware of the locust campaigns they support).

Although damage to farmers and their village economies can be extreme, at larger social scales the concern for desert locusts is nominal. Within the general public, urban consumers have little stake, since the brunt of losses caused by desert locusts in Eritrea is to the rural subsistence farmers and local markets; there is the possibility of small scarcities of staple grains for a limited period of time (if control is conducted against swarms). Eritrea's light food industry does not depend heavily on Eritrean farming, so the effect of desert locust infestations is negligible. Few impacts would occur to lenders and bankers because they are not involved in most of agrarian Eritrea, and insurance for locust-induced losses does not exist.

The network of agricultural stakeholders at levels higher than the village appears to have only marginal concern about locusts. Pesticide manufacturers view desert locust control as an unpredictable but intermittently lucrative market. The customers, however, in the case of locust control in Eritrea and many other desert locust-affected countries, are primarily bilateral and multilateral aid agencies that each adhere to various national and international environmental guidelines. This constricts the market to the manufacturers of those insecticides that are on the various lists. Even with a relatively narrow range of competition, manufacturers generally see desert locusts as a specialized segment of an already established market in crop protection, and during recessions their interest wanes in the absence of imminent profit potential.

Agricultural markets have been largely protected from the effects of desert locust infestations during the last decade, partly because of the patchy and localized extent of crop losses, and the success of some control campaigns at averting swarm development within the country (Showler 2001a, c) and at eliminating swarms that arrived from other countries *e.g.*, Chad 1995, (FAO 1995).

There are three groups of pesticide applicators during desert locust campaigns in Eritrea: farmers, government personnel, and, for aerial operations, the Desert Locust Control Organization for Eastern Africa (DLCO-EA). Farmers-as-applicators can benefit economically, but the cost of insecticides, supplied by the government, is especially high for the majority that conduct subsistence or small local-market farming. Ministry of Agriculture agents who conduct control operations do not profit from control campaigns, but they (and farmers) receive training to lessen waste of insecticide and to reduce the environmental and health hazards (Showler 1995a). The DLCO-EA is a parastatal organization that specializes in aerial operations and is funded, in theory, by member countries, though few regularly pay their annual fees. (Eritrea pays.)

Swarms of desert locusts that develop and fly from one country to another can result in accusations by the country into which the swarms arrive, and embarrassment of the country that allowed a localized infestation or a regional outbreak to achieve cross-regional plague status. Such is of concern to Eritrea, because it harbors prolific breeding areas on the Red Sea coastal plains (Pedgly 1981). It is also an important consideration in a region notorious for instability and armed conflict (Showler 2001b). Hostile neighboring countries' relations could deteriorate if swarms from one invade the other, or relations could improve if both countries put aside their differences for the cause of locust control on a mutual border.

Irkutsk.— A great majority of agricultural producers in Irkutsk belong to large cooperatives which emerged from the communist-era collectives. Although there are some significant

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market-economy incentives (*e.g.*, possibility of gaining benefits from selling the agricultural production in a free market), the cooperatives are still functioning mostly as government-owned enterprises, and agriculture remains one of the most heavily subsidized industries in Russia. Therefore, agriculturists consider the PPS activities as a service provided by the federal government, and insecticide purchase would have been impossible without subsidies. That is why grasshopper control on "private" lands is currently reduced to a bare minimum. Since the insecticides for grasshopper control are provided by the federal government, the cooperatives are not necessarily interested in their environmentally and economically rational use. As a result, frequent overdosing and contamination may occur. The government tries to promote the wise use of the insecticides through PPS advice and supervision of control operations. The lack of the economic motivation in end-users is probably one of the primary reasons why the progressive strategies of grasshopper control aimed at insecticide reduction (*e.g.*, RAATs) are slow to be implemented in Russia, although these methods were first tried in Irkutsk in 1997 (Latchininsky 2000a, c; Lockwood *et al.* 2000b).

For small private producers, a grasshopper outbreak may be a real disaster, because they are not eligible for government subsidies for acridid control. Food security, rather than food quality, is perceived as the major issue. People remember that in the beginning of the 1990s, all main foods were rationed, and lines for bread were interminable. Therefore, the public perception of grasshopper infestations generally advocates "the ends justifying the means". Environmentalists' concerns regarding long term consequences of massive grasshopper control programs rarely find their way into the media, but in Irkutsk this matter is important because of the proximity to Lake Baikal. The lake holds >20% of the world's freshwater supply and is inhabited by >2,000 animal and plant species, 80% of which are endemic.

From an agrochemical business perspective, the Irkutsk Oblast represents a temporally erratic market. For example, in 1994 the 325,700 ha treated in Irkutsk represented 61% of the area sprayed for grasshoppers in Russia. During recent years, Russia's Oblast governments obtained increasing liberty and resources to work directly with pesticide producers, which might increase the attractiveness of local grasshopper control to agrochemical companies.

Federal governmental agencies, especially the Ministry of Agriculture, perceive grasshopper control as being an element of routine crop protection. When a severe acridid outbreak occurs, the federal government can allocate resources from its emergency relief budget. For example, the centralized locust and grasshopper management budget in 2001 in Russia (US $18 million) was 4X higher than the corresponding budget of 2000. The Ministry of Agriculture registers the appropriate insecticides, provides guidelines for their optimal use and supervises control programs through the PPS specialists. Grasshopper outbreaks are attentively reported by the media, so a failure in a campaign can trigger the firing of personnel.

Wyoming.— Because of limited off-farm/ranch support, the agricultural producer in Wyoming is the most relevant scale at which the issue of sustainability arises. However, as a consequence of decentralized pest management, a more intensive discussion of the obligations of a "good neighbor" has emerged. Because acridids are mobile, albeit far less than locusts, the actions or inaction of one farm/ranch can have significant effects on adjoining lands. This tension is particularly acute when grasshopper infestations on federal lands (leased to ranchers) threaten neighboring, private farmlands. This is the only situation in which the federal government still subsidizes grasshopper control, at a cost up to 20X that which a private landowner typically pays to protect rangeland forage.

In the USA, food security is not a key concern, so grasshopper-induced losses are not perceived as a threat. Consumers regard agriculture in several, sometimes contradictory, ways. The primary focus is that food and fiber production are merely business ventures with the attendant risks and potential profits. The consumer also expresses strong affection for family farms, although grasshopper outbreaks are not generally perceived as putting this cultural icon at risk. The greatest concern of the consumer is not food quantity but food safety, so pressure to reduce pesticide residues on food has become intense. The public demand for a diminished federal government, which precipitated the termination of subsidized grasshopper control, appears to have led to a decrease in the amounts of insecticide used for grasshopper control and a consequent increase in food safety.

From a business perspective, although the area of land that can become infested with rangeland grasshoppers is immense (13 million ha in Wyoming alone, which is ~15% of the area that can become infested in the western US), the attendant agrochemical market is extremely erratic and low-value. Moreover, the Food Quality Protection Act limits the total human exposure allowed for any given pesticide, so companies tend to focus their products on commodities with more consistent pest problems and higher values. As such, few insecticides are available for rangeland grasshopper control; the only chemical to be registered for rangeland grasshopper control in the last 25 y is diflubenzuron. The greater business concern occurs at the community (town or county) level, where the losses to farmers and ranchers may directly affect the economic viability of supporting businesses. In extreme cases where a rancher loses his land, the increasingly likely outcome is some form of absentee ownership or land development (*e.g.*, subdivision into parcels for housing), neither of which appear to be welcomed by, or beneficial to, the local community.

Federal agencies generally perceive agriculture to be either a form of business that contributes to the balance of trade or as a threat to environmental health. Although Wyoming government agencies share these perspectives, they also reflect the cultural value of ranching as a way of life. At the county level, government agencies such as the weed and pest districts are directly accountable to local boards, making their link to agriculture, and their concern for grasshopper outbreaks, much more in harmony with the perspectives of the producers. The notion that ranching may actually sustain the open vistas that attract tourists – the

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state's second leading source of income, after mining – seems to be growing in importance. Hence, the motivation to assist ranching families during episodes of grasshopper infestations may yet find a place in the state's priorities.

Synthesis.— In terms of the social scale, three important commonalities and at least one crucial difference exist among the case studies. In all three cases the individual farm or ranch appears to function as the fundamental unit of concern in acridid pest management. The varied interests, ecologies, and economics of local production units along with the spatial heterogeneity of grasshopper and locust populations mean that effective aggregations of farms or ranches into larger management units are unlikely. Hence, an effective pest management system will need to consider the diverse concerns of individual producers. Another option which is frequently practiced is the creation of management units by administrative aggregation (*e.g*, rayons in Irkutsk), which is far from being optimal since acridid infestations do not respect administrative boundaries.

All three sociological settings appear to place value on being a responsible neighbor, which generates a social obligation to keep acridid outbreaks from spreading to adjacent lands. This notion is furthered by a sense of pride in being a good manager, able to effectively maintain control of acridid outbreaks within geopolitical borders. In the case of Eritrea, to allow a locust swarm to invade a neighboring country undermines a sense of national self-esteem. In Irkutsk and Wyoming, the spatial scale is more localized as a function of the mobility of the pests, but there remains a clear obligation for individual landholders, including collectives and governments, to keep acridid populations from moving into adjacent fields or crops.

None of the systems examined appear to be driven by the agrochemical industry. Although acridid infestations are locally severe and these patches can occur across large areas, the temporally erratic nature of outbreaks and the generally low cash-value agricultural systems being infested, mean that the market value for insecticides used in acridid control is of relatively minor importance to the companies. Indeed, insecticides are registered as acridicides because of several factors, including: 1) the worldwide distribution of acridids creates a more consistent global market than what emerges in any particular region, 2) the insecticides that function as acridicides often have a more consistent and profitable market in other pest systems, 3) the high profile nature of acridid outbreaks provides an opportunity for companies to gain attention.

The most important difference among the three analyzed systems is the relationship between people and food. In Eritrea, food security is central. In Wyoming, the material existence of food is taken for granted, and food quality becomes paramount. Irkutsk represents an intermediate case, where hunger is not as potentially imminent as in Eritrea, but the quality of food is not as important as in Wyoming. Thus, whether food quantity or food quality is the underlying concern of an agricultural system plays a central role in defining the nature of concern and the pest management practices associated with an acridid infestation.

Interest Scale

Justifying and sustaining control of acridid outbreaks is related to the perceived purpose of the intervention by the individuals involved. In simple terms, the most relevant interests pertaining to acridid pest management include: economic (as conventionally expressed in terms of monetary units), environmental (usually expressed in terms of clean air and water, soil conservation, and biodiversity), and cultural (typically captured in terms of tradition, law/politics, religion, and ethics). As with the social scale, an individual or group may hold various perspectives, for example having compelling interests in both economic stability and environmental health. Moreover, the various interests that interact to derive value from acridid pest management are not necessarily opposed. For example, what is economically profitable may converge with practices that are environmentally sound if a long term perspective is taken.

Eritrea.— The two primary economic interests relevant to locust management in Eritrea represent the ends of the spectrum. At one end are the agriculturalists. The majority of Eritrean producers are subsistence and small local-market farmers. The intermediate economic interests of the food industry, markets, and pesticide manufacturers/applicators are limited. At the other end of the economic spectrum are the international development organizations and the idea that development is disaster-driven. Long term development needs are often largely ignored or unknown until problems magnify into disasters. In the instance of desert locust control, for the last decade development efforts have been addressing control aspects, including training, logistics, management, scouting, equipment maintenance, research, contingency planning and communication (OTA 1990, FAO/EMPRES 1998, Showler 2001a). Disasters are high profile in international bilateral and multilateral development agencies, and funds are easier to obtain for portfolios that were created in the immediate wake of a disaster. Disaster-driven projects are constructed, and as interest wanes in the locust issue, the staff of these programs might seek to ensure job security by not aggressively tackling the tasks at hand, or by rationalizing the need for continuing staffed programs.

International development represents an important market for a wide variety of businesses. In locust control, pesticide manufacturers, aircraft charters, consultants, universities, vehicle parts dealers, and distributors of navigational equipment, radios, safety gear, and other items can all profit to some extent from locust control, especially during large-scale campaigns. Government agencies and consulting and contracting firms that capitalize on government spending profit from overhead payment. In this connection, it must be noted that Eritrea is an anomaly in Africa, having largely rejected development assistance originating from donor countries. Thus Eritrea became less profitable to the international development industry than many of its neighbors.

At a global scale, desert locust outbreaks, if limited, are

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viewed by international aid agencies both as opportunities for making contributions to affected countries and thereby building closer relations, and as a costly and difficult problem that can endure for years if an outbreak becomes a plague. The cost-benefit of desert locust control has been intensively debated for the last decade, and there is still no consensus on whether desert locust control merits the sort of financial commitments it has been receiving.

Because Eritrea is a relatively new country, having become independent in 1992, and because hostilities have often disrupted government affairs, Eritrea has not yet completely developed its policies on environmental protection. However, there are two tiers of government agencies that deal with Eritrea's environment. The first is Eritrean Ministries. The Ministry of Natural Resources and the Environment is less involved in protection of the environment during locust outbreaks than the Ministry of Agriculture. The Ministry of Agriculture has been trained in aspects of desert locust control in bilateral and multilateral programs, including environmental concerns, biological control, proactive intervention, and the use of safety equipment (USAID 1992, FAO/EMPRES 1998). Environmental concerns are carefully considered prior to the initiation of control operations. In the 1997-1998 campaign, some hopper bands were not treated immediately so that risks to humans and livestock could be avoided, or so that national researchers on mycopesticides could conduct efficacy trials (Swanson 1997).

Agencies typically impose stipulations, sometimes aimed at strengthening environmental protection, with their aid packages. For example, some donor agencies helped to eliminate use of dieldrin against desert locusts during the 1986-1989 campaign by withholding locust control aid if chlorinated hydrocarbon compounds were being applied. Also, donors and multilateral organizations have contributed relatively short residual insecticides and have encouraged and supported projects for finding and developing indigenous isolates of *Metarhizium* spp. in Eritrea. Nongovernmental organizations were largely discontinued voluntarily by the government of Eritrea, and those that have returned did so in the aftermath of the 1998-2000 war with Ethiopia.

As with other sudden and severe natural disasters, the arrival of locust swarms is an unforgettable event to those who experience it. In a cultural context, the appearance of locust swarms during the growing season is dreaded, and this might be intensified by references to the destructive, possibly punitive, power of plagues of locusts in the Bible and the Koran, the holy books of the two predominant religions in Eritrea. Although desert locust invasions are important elements of local history, at a broader cultural scale-locust management is of little concern. Desert locust infestations have a negligible role among the nine Eritrean ethnic groups. Some people consumed locusts, but only during the infrequent outbreaks. Also, locust control in Eritrea does not impinge upon land use patterns. The main desert locust breeding areas occur along the harsh coastal desert which supports only small subsistence villages, remote salt-harvesting shanties, and nomad camps. Some areas of Eritrea, however, have been off-limits to Ministry of Agriculture desert locust surveys because they are strewn with buried land mines since the war for independence, or because of tensions along the western border with Sudan. Finally, because desert locust outbreaks are sporadic and recession periods can be long, locust control is unlikely to have a significant cultural impact on future generations in Eritrea.

Irkutsk.— Grasshopper outbreaks cause economic losses to agricultural producers, especially to the small proportion of private farmers. For agrochemical companies, outbreaks represent potential, if erratic, profit. For example, in 1994 DowElanco sold 60t of Dursban 480EC (chlorpyrifos) to the Irkutsk Oblast government, which purchased it using a federal subsidy (emergency fund). This amount of insecticide was enough to treat 120,000 ha, or 37% of the total area treated in 1994. The purchase and use were somewhat peculiar in this case because in 1994 Dursban was not yet registered for grasshopper control in Russia. However, the company managed to obtain an "emergency temporary use permit" through the Ministry of Agriculture, based on insecticide performance data collected in Africa.

Outbreaks are also potential sources of profit for individuals associated with treatments. In particular, aerial applicators may actively pursue the possibility of contracting treatments on the largest possible area. In 1994, 36 Antonov-2 aircraft belonging to the Irkutsk territorial agricultural aviation division were engaged in grasshopper treatments.

For PPS specialists, a grasshopper outbreak requires intensified efforts in terms of surveys and treatment supervision. As a rule, public opinion is inclined to blame the PPS specialists (especially the forecasters) for missing upsurges in grasshopper populations. An outbreak is always "unexpected" and comes "out of the blue". Only when the situation becomes severe and potentially uncontrollable are large scale treatments applied. To the general public, PPS specialists are responsible for lags between outbreaks and control, although in most cases they are unable to adequately monitor and control grasshopper outbreaks without extra funding. Thus, grasshopper outbreaks for PPS specialists mean a period of rigorous attention and labor during the field season. At the same time, paradoxically, it is a rare opportunity for them to attract public attention to the challenges of their work. For example, in 1994 the Irkutsk PPS was able to completely renew its vehicle pool and purchase new equipment and supplies using emergency funds. This was unimaginable without a grasshopper outbreak reaching crisis proportions. When an outbreak declines, the PPS specialists become "the heroes that won the battle", an image that lasts until the start of a new outbreak.

Although southern Irkutsk is an ecologically sensitive area because of its proximity to Lake Baikal, environmental concerns do not play a significant role in the implementation of chemical grasshopper control. A grasshopper outbreak is perceived as being a calamity which must be stopped at any cost. Despite this, all insecticides used in Irkutsk must be registered in Russia through a process of extensive analysis by ecologists and other relevant scientists. Adherence to the provisions for correct use of these registered chemicals is

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supervised by the PPS.

In cultural terms, grasshoppers and locusts draw maximum attention when they appear in swarms in villages or cities. That was the case in 1999 in Kazakhstan, when huge swarms of the Italian locust, *Calliptamus italicus* (L.), invaded the national capital. The locusts even influenced women's fashion; the swarming insects made skirts or open blouses untenable. The arrival of spectacular swarms cost the Minister of Agriculture of Kazakhstan his career — he was fired by the President. Earlier, anecdotal records relate that in 1930, when immense swarms of the desert locust reached the Transcaucasia (Armenia) and perished in the mountainous lakes, local people used the cadaver masses as fuel to heat their houses instead of wood (Predtechensky 1935). Such extreme situations have not reached Irkutsk, although some villages were heavily infested by grasshoppers in 1994 and 2000.

Wyoming.— The economics of grasshopper outbreaks are complex. For the rancher, an outbreak represents an economic loss. For insecticide applicators and agrochemical companies and retailers, grasshopper outbreaks represent potentially significant market opportunities. However, with the loss of the federal subsidy for grasshopper control, the economic perspectives have been revised. Whereas the agrochemical industry once equated higher prices with greater profits, they now realize that the market for their products and services is constrained by total cost. Unless the price of insecticide and application are less than US$2.50/ha, grasshopper control cannot be profitably employed on most Wyoming rangelands. Although there was initial resistance to using less chemical per hectare and treating only a fraction of the infested land, the RAAT approach is now widely seen as the only viable method allowing ranchers to consider an intervention. The widespread adoption of RAATs by ranchers, its acceptance by agrochemical companies (some of who now label their products specifically for this method), and its endorsement by the [US] National Grasshopper Management Board (1998) demonstrate that the "less is more" notion of economics has begun to prevail.

Environmental interests almost always perceive rangeland grasshopper control programs to be a net loss to natural ecosystems. In this regard, the development of RAATs represents a strategy of benefit in terms of both economic and environmental values. In the last 2 y in Wyoming, just one county (Platte) managed to control grasshoppers on 25,000 ha with 13.5 fewer tonnes of insecticide and savings of US$100,000, compared to what would have been necessary with traditional application methods. Government agencies and private enterprises are reluctant to acknowledge the possibility that grasshopper infestations represent risks to other elements of the ecosystem. There has been essentially no recognition that grasshopper infestations could damage endangered plants and compete with endangered birds [*e.g.*, sage grouse depend on forbs during their juvenile development, and these plants can be virtually eliminated during grasshopper outbreaks (Pfadt 1994)]. However, other trends suggest that perhaps agricultural, economic and environmental concerns are converging in Wyoming. The preservation of habitats, which is vital to conserving native species, has come to depend on viable ranching operations, which stand between land developers and natural landscapes.

Grasshopper management in Wyoming and the rest of the western states is encouraged and constrained by various cultural perspectives. Many Americans perceive agriculture as the ultimate manifestation of free enterprise capitalism, with farms and ranches representing an idealized form of economic "rugged individualism". There is a deep recognition of the family farm as the foundation upon which the country was built, a perspective celebrated in art and literature (Lockwood 1999). The place of grasshoppers in the cultural psyche was established by the devastating plagues of the Rocky Mountain locust, *Melanoplus spretus* (Walsh). The allusions to Biblical plagues and the wrath of an angry God were part of the desperate attempts to understand and control the swarms of Rocky Mountain locust in the late 1800s. Also, the western USA is well-endowed with public lands — parks, refuges, monuments, forests, and grasslands — owned by the federal government and hence by the people. Although the National Parks and Monuments are highly valued, the health of desert grasslands, sagebrush steppe, and mixed-grass prairie in Wyoming have become matters of increasing concern. These public lands are being perceived as a collective resource, and the extraction of forage by livestock (a process that is undermined by grasshopper infestations) is seen as only one viable use of these ecosystems. As Americans come to more fully realize that there are no unclaimed lands or open frontiers into which the next generation can move, the management of grasshopper outbreaks becomes a compelling case of the cultural challenge to find ways of living with natural processes manifested by native species.

Synthesis.— A summary of the values that are put at risk during an acridid outbreak suggests that in the various systems a similar range of costs and benefits arises. If we were to set a subjective scale of -10 through 10 (-10 = devastating loss; 10 = tremendous gain), an acridid outbreak might represent an event ranging from -10 to 0 for a farmer or rancher in the three described cases. That is, in each of these instances the agriculturalist has nothing to gain (even if the infestation is rapidly and cheaply controlled, there is no net gain, only the avoidance of loss) and everything to lose (an unchecked infestation means the loss of the entire farm or ranch). In a similar manner, the general public has little to gain from infested lands, although a diversified food production system would suggest that their losses are likely to be less than those of individual farmers or ranchers. So outcomes ranging from 0 to -4 might be reasonably assigned, with the greater losses being associated with more local interests and markets. In contrast, agrochemical industries could be reasonably described as having a range of outcomes from 0 to 2 during an acridid outbreak. These companies may gain nothing in terms of product sales, and even during a severe situation the total gain to the company would be quite modest in the context of their overall economics and public relations. The other major player is the government, which, as with the public, has gains or losses correlated with their proximity to the acridid

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infestation. However, the government potentially stands to gain political allegiance from a well-managed control program, while arguably having even more to lose if their interventions are ineffective. Hence, we would suggest that governments face a range from -5 to 3 in terms of their likely losses and gains.

Temporal Scale

The time over which one assesses the value of acridid pest management is key to whether the program is perceived as being sustainable. The costs and benefits of control can vary dramatically as a function of temporal perspective. What may appear to be a cost at one time (*e.g.*, immediate suppression of a nontarget species) may eventually disappear (*e.g.*, a nontarget species may recolonize the treatment area). And the same may hold for benefits [*e.g.*, suppression of a grasshopper outbreak with a broad-spectrum insecticide may yield immediate profits, but the elimination of natural enemies can lead to more severe outbreaks over the course of years (Lockwood *et al.* 1988)]. The time scales of relevance to acridid control are: immediate (hours or days), short-term (within a season), annual, long term (2-10 y) and intergenerational.

Eritrea.— At the scale of days, the greatest concern regarding locust control arises at the local level. During outbreaks, the importance of control is particular to each farmer. The sense of urgency is largely a function of how far the swarms or hopper bands are from his/her fields and the time of year (vulnerability of the crop). Swarms and hopper bands close enough to reach the fields within days, generally arouse considerable concern in farmers. Because of the sudden and intensive nature of desert locust damage to crops and this locust's unpredictable gregarization, crop protection capabilities can be overwhelmed if proactive measures are not applied against breeding populations.

Although the pivotal time during which desert locust damage occurs lasts only hours, the primary temporal scale of concern is the growing season, which reflects the nature of the investment that is at risk during desert locust infestations. Within a season, there are times of great risk (just before harvest), lesser risk (seedling stage which can be replanted) and no risk (after harvest). The sporadic occurrence of desert locust outbreaks, coupled with the localized damage and the possibility that the crop might not be at an economically vulnerable stage, translates into a reduced chance of suffering economic loss. Using illustrative, liberal probabilities, assuming that the probability of an outbreak causing serious damage at a particular farm in Eritrea during a given year is 0.3, the probability of desert locusts invading a given farmer's crop is 0.25, and the probability that the brief visitation by the locusts occurs during an economically critical stage of the crop and causes serious damage is 0.2, then the chance of significant crop loss to a farmer in a given year at the local level is 0.015.

At the subsistence level, crop failure at a critical juncture can cost farmers and their families their livelihoods, and if severe and combined with drought, their lives. In Eritrea's subsistence society, however, complete crop loss by a farmer would likely result in assistance from the extended family. If a desert locust infestation were of sufficient magnitude to overcome the capacities of extended families to alleviate, or if this relief system were disrupted by war, external assistance would be required or famine could ensue. For example, in 1997-1998, rebels holding Sudan's Red Sea coastal plains reported food shortages as a result of crop losses to the desert locust.

The effects of locust outbreaks and management may also persist across longer time scales. Economic ramifications of massive crop loss in one season to individual farmers and their families can extend for years if the farmer incurs large debts, or if the farm is lost. Also, serious defoliation of perennial crops such as citrus can cause declines in production for years after (Steedman 1988, USAID 1991). Desert locust outbreaks are unlikely to have intergenerational consequences, except in instances where specific families have been forced to cease farming as a livelihood as a result of severe crop losses, usually combined with, and principally because of, drought. Finally, during extended lulls in desert locust activity, the readiness of national locust control units can deteriorate through neglect.

Irkutsk.— Grasshopper control in Russia is understood to be a service rendered by the government (FPPS), and the expectations of immediate relief after a control action are high. Currently, materials for use in Russia include ~20 products belonging to several chemical classes. Acridicides used in the 1970s and 1980s were organochlorines, organophosphates and pyrethroids with rapid knock-down effect. Usually, >90% mortality was achieved within 24 h of treatment. New compounds entering the market in the 1990s [insect growth regulators (IGRs), phenyl pyrazoles and chlornicotinyls] are generally slower: maximum mortality occurs 1-2 wk after application, but they have a longer protective effect. This latter advantage is not always appreciated, even by the specialists. A dramatic change in psychology is needed to convince the agriculturists of the advantages of these new compounds in the context of preventative or proactive strategies.

Of about 50 grasshopper species inhabiting Irkutsk, only six are recognized as economic pests. Nevertheless, dogma has it that the only good grasshopper is a dead one. No grasshoppers are considered beneficial in Russia (*e.g.*, as weed consumers) although their role in nutrient cycling is recognized (Kopaneva 1975). That is why the targeted level of efficacy of grasshopper control is 85%, and the need for immediate control is perceived to be urgent.

The annual scale is one of the most frequently used temporal context scales of grasshopper management in Russia. The summer adult and autumn egg-pod surveys are used to estimate the extent of the possible infestation in the following year. Based on the results of these surveys, the volume of insecticides needed is estimated and the relevant decision on insecticide purchase is made at the federal level.

We can apply reasonably generous probabilities to estimate the probability that a farmer will suffer serious losses from grasshoppers in Irkutsk. Assuming that the probability of serious crop loss to an Irkutsk farmer from a grasshopper

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outbreak during a given year is 0.1 and the probability of grasshoppers reaching damaging population densities on a given farmer's land is 0.1 (this value could be as high as 0.3 in some areas), then the chance of significant forage loss in a given year at the local level is 0.01. Through largely unresolved factors, some locust infestations may result in high densities without causing feeding damage, but this situation is virtually never observed with grasshopper outbreaks.

Considerations of economics at the Oblast scale and above are also translated into annualized figures. The cost-benefit analysis of grasshopper management was virtually impossible until the last few years. Even the massive campaign of 1994 in Irkutsk yielded no economic assessments. However, with the progress of a market agriculture, attempts to evaluate management actions have recently been made on a regional basis. We do not have access to the relevant figures for Irkutsk, but for a similar Oblast (Novosibirsk is 1,000 km due west of Irkutsk) yearly treatment and cost estimates have been developed. Acridid control in Novosibirsk in 2000 was conducted on 140,000 ha at a cost of US $1.7 million, coming from both federal and Oblast's budgets (Latchininsky 2000).

Wyoming.— The expectation of most ranchers has been that grasshopper control will yield rapid suppression. Malathion and carbaryl provided quick control, and this temporal perspective was one of the factors that limited the acceptance of *Nosema locustae*, a pathogen that took weeks to yield maximum mortality (Lockwood *et al.* 1999). The use of slower-acting IGRs has required an intensive educational effort to ensure that ranchers understand the nature of the product and the course of control. In addition, IGRs must be applied to nymphal populations, compressing the optimal time for treatment to ~3 wk.

Ranchers are aware of alternative strategies for suppressing rangeland grasshoppers. Buying hay, reducing their herds, and other strategies to manage inputs are considered viable approaches in some cases, and these tactics clearly reflect a longer term perspective than would be suggested by the expectation of immediate control. Many ranchers have been in operation for several generations, and one of the highest priorities in their decision making is to assure that the land stays in the family. Although economically poor decisions can cause the loss of a ranch, rather than choosing options that maximize profits, it appears that many ranchers attempt to maximize the likelihood of retaining their land – which is not necessarily the same decision that would maximize income.

The direct benefits of control can accrue rapidly compared to the indirect costs. Historical analyses of grasshopper infestations in Wyoming suggest that in most locations grasshopper populations usually do not persist beyond one year, so the economic returns of a control program must exceed the costs within the year of application (Zimmerman 1999). However, a study in Wyoming and Montana (Lockwood *et al.* 1988) showed that the large scale use of broad spectrum insecticides could, over the course of years, make grasshopper outbreaks more frequent and severe by suppressing natural enemies and creating "predator/parasitoid-free" space in which grasshopper populations could rapidly recover.

The probability of serious damage by rangeland grasshoppers in Wyoming varies markedly with location. Based on reasonable estimates, we can assume that the probability of an outbreak occurring in Wyoming during a given year is 0.2 and the probability of rangeland grasshoppers reaching damaging population densities on a given rancher's land is 0.1. (Because grasshoppers consistently outbreak in particular areas, this value would be as high as 0.5 for some ranchers.) As such, the chance of significant forage loss in a given year at the local level is 0.02.

Thus, it appears that grasshopper management in Wyoming is a function of time scales ranging from days to decades. The notion of a sustainable program of grasshopper management at an intergenerational temporal scale is at least consistent with the perspectives of some agricultural producers. However, the nature of agricultural economics in the USA is such that annual profits may be necessary to make payments against loans. As such, the goal of long term (decades) sustainability becomes a pointless abstraction when faced with the prospect of losing the land to creditors because short-term (annual) profits are insufficient.

Synthesis.— The temporal scales at which acridid pest management systems are expected to function are similar in the three case studies, although there are some important differences. In all settings, the spatially small social scale (*i.e.*, the farm or ranch) functionally compresses the temporal scale, such that the need for effective intervention is imminent during an infestation. Given the heterogeneous nature of acridid infestations, an entire region may be able to withstand an outbreak by "averaging out" the areas of loss with those producers that are less affected. However, the rapidity of damage by acridids and the lack of capacity for individual farms and ranches to absorb significant pest losses, means that control measures must be taken quickly to be of value. Interestingly, all three case studies generated estimates of serious damage by acridids to any particular farm or ranch in a given year as 0.01 to 0.02, suggesting a further similarity among these areas with respect to temporal considerations.

The mobility of locusts and the univoltinism of grasshoppers serve to compress the window of opportunity for effective pest management interventions. In the case of desert locusts, the chance to implement meaningful control at the scale of the individual farm may be a matter of hours after a locust swarm arrives. With grasshoppers, the time-frame is somewhat more generous, but the optimal window of opportunity for management rarely exceeds 10 d. Without significant and extensive preparations based on a thorough scientific foundation, government agencies are unable to provide the means for controlling acridid infestations within these temporal parameters.

Setting aside the crisis of an ongoing acridid infestation, the individual agriculturalist still labors under the demands of a compressed temporal scale. In light of the need for annual productivity, in order to meet either subsistence or economic demands, the longest temporal unit of concern is a single growing season. Although farmers and ranchers may conceptualize the need for longer-term strategies, if

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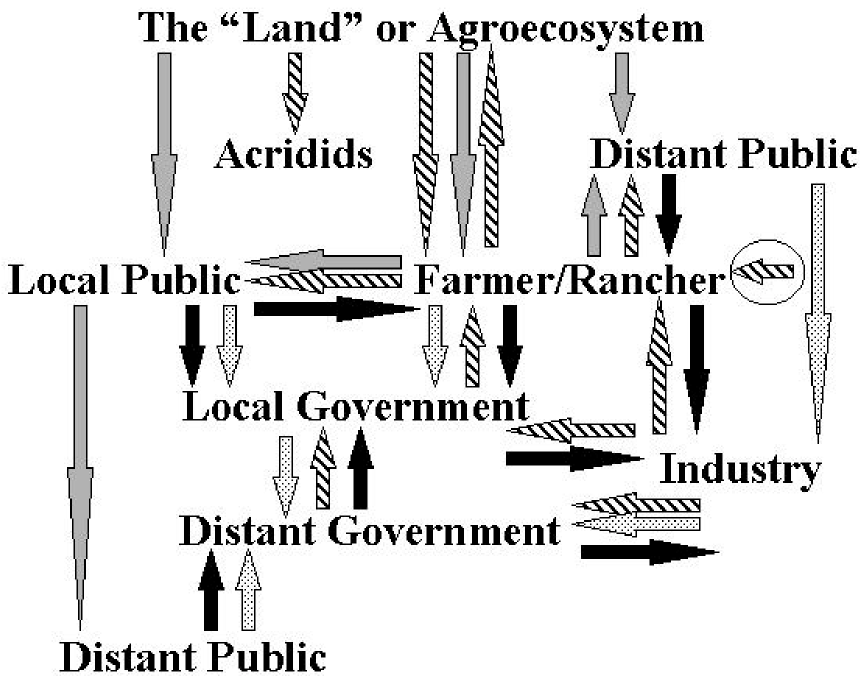

Fig. 2. A generalized model of the agents and processes that define acridid pest management. Black arrows indicate the flow of funds; hatched arrows indicate the flow of materials (food, equipment, supplies, insecticides, etc.; the circled arrow indicates the cycle of subsistence agriculture); gray arrows indicate the flow of amenity (e.g., pleasure, happiness, satisfaction); stippled arrows indicate the flow of allegiance (political favors and alliances). Because science informs every stakeholder and process in this model, it cannot be easily depicted, but the pervasive influence of scientific information should not be overlooked. The importance of various agents and processes differs markedly among countries (see text).

they are driven from their land by hunger or debt in the course of a single year's acridid infestations, far-sighted goals become moot. This is probably one of the most important obstacles to sustainability — if the fundamental unit of acridid management (the farm or ranch) cannot perceive or, in some cases, afford long term management efforts, any program that relies solely on this temporal context is ultimately doomed.

Conclusions

Fig. 2 reflects some of the important patterns in the flow of values (monetary, material, political, and amenity) among the principal elements of acridid pest management systems. We note the absence of a critical factor that influences all of the processes. Science is such a pervasive input its role cannot be simply depicted. Farmers, publics, industries, and governments all rely on science as a primary source of information. Without reliable scientific studies the sustainability of any pest management system is compromised. Although the relative importance of various stakeholders and transfers in this system differs among places, it is evident that agriculturalists in Eritrea, Irkutsk, and Wyoming face some common challenges. Furthermore, there appear to be some general and promising approaches to addressing these difficulties. The site-specific and local conditions that define farms and ranches in each case-study area suggest that there is a sufficient basis of unifying concerns and values to propose some principles that are likely to promote sustainable acridid pest management systems.

Keys to Sustainable Acridid Pest Management

Strategic decentralization.— In all of the case studies, it is evident that a top-down government-centered infrastructure is being decentralized. The critical process in this transition will be creating the opportunity for a systematic restructuring of management systems. That is, the role of government should be in facilitating the transfer of knowledge, technology, and power to the agriculturalists who are most severely affected by acridid infestations. This responsibility, to foster the development of a pest management system founded on local control, is fundamentally different than simply abandoning the historic programs. The dominant traditional role of government cannot be abrogated to the local level, where there has been little experience, context, or expertise. That is, the national and international governments have either intentionally or unwittingly fostered local dependency, and it is the duty of these govern-

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ments to proactively invest in the educational programs necessary for local systems to arise in an effective manner.

The bottom-up approach to restructuring acridid pest managements suggests that we are inverting the presumption of responsibility. That is, rather than assuming that the highest level of political organization is the proper context for intervention, the bottom-up system presumes that the most local agent is the responsible party. Such a presumption is set aside if and when it can be demonstrated that the next highest social or political level is more effective, efficient, or knowledgeable. Coordination at this higher level may avoid duplication of efforts, create meaningful standards, or access buying opportunities. For example, the prevention/elimination of locust upsurges may require information and action coordinated across an entire region. In particular, proactive or preventive strategies for locust management require survey and treatment of remote, uncultivated and even uninhabited breeding areas, which necessitates organization above the purely local level. In a similar sense, survey for grasshopper infestations may be a responsibility that can be effectively shared among locales, and consistency of methodology allows meaningful comparisons among regions.

Higher level coordination may also prevent an inverse "tragedy of the commons". A "tragedy of the commons" typically develops when the benefits of an action are individualized and the costs are collectivized, or in economic terms, externalized. An inversion of this situation arises when the benefits of an action are collectivized, but the costs are individualized. Grasshopper and locust control can be obstructed if the costs for a particular locale's efforts to suppress an infestation are borne entirely by the local people, while the benefits of the control operations are spread among other communities or regional populations that did not experience infestations because the outbreak was contained within a limited area.

In all of these examples of how coordinated efforts may be justified, the nature and extent of higher level organization should emerge from site-specific and culturally relevant opportunities. In Eritrea, zonal offices may allow a coordinated response to an arriving swarm; in Irkutsk, Oblast plant protection offices may be well positioned to orchestrate logistics; and in Wyoming, weed and pest districts may be effective in developing education and training programs. There are examples of highly centralized acridid management systems which function well (*e.g.*, the Australian Plague Locust Commission and the National Plant Protection Center in Uzbekistan). These governmental organizations benefit from steady, renewable function and therefore appear to be sustainable. The other important reason for the viability of these centralized management models is the high frequency of locust infestations in the affected countries (~80% of the years have a serious outbreak) which requires continuous monitoring and control efforts. Such models are not highly applicable for locales with lower pest infestation frequency, such as those analyzed in the present study.

Subsistence and persistence.— The difference between agricultural producers in rich and poor countries translates into the difference between growing food to prevent hunger and producing food for market. Is it possible for people engaged in growing crops for local consumption to learn from ranchers engaged in producing cattle for economic gain? The former have been termed "subsistence" agriculturalists, whose goal is to subsist on the land. Likewise, it may well be that the latter should be thought of as "persistence" agriculturalists, whose goal is often to continue a way of life on the land. Persistence agriculture demands a certain level of economic return, but it appears common that ranchers make decisions to optimize the perceived likelihood of retaining their land, rather than maximizing their profits. Hence, subsistence and persistence agriculture are fundamentally linked by the necessity of managing resources so as to sustain a human presence on the land – and in this way, the Eritrean farmer, the Irkutsk farmer-grazier, and the Wyoming rancher must ultimately manage acridid outbreaks in an environmentally sustainable manner.

Industry's role.— The case studies show that agrochemical industries are relatively minor players with limited interests in the developing infrastructure and human resources. Whether they market to international agencies, federal governments, local stations, or individual producers, their potential profits are constrained by the spatiotemporal patterns and economics of locust and grasshopper populations and control. Companies producing biological control agents may have a significantly greater stake in the form that acridid pest management takes, as these industries often have a greater proportion of their business dependent on acridid control.

Science's role.— Finally, science has a key role in sustainable acridid pest management. An approach that is socially and economically sound but scientifically or technically flawed (*e.g.*, erodes vital ecological processes, fails to provide adequate suppression of pests, or overlooks important elements of population dynamics) will not be sustainable. Seemingly viable socioeconomic systems of pest management can actually exacerbate the frequency, duration, or severity of acridid outbreaks if scientifically generated perspectives are not incorporated into the methods (Lockwood *et al.* 1988). Science should inform not only the methods of survey and management but the public and government perceptions of the program. Expectations for results that are technically impossible or scientifically ill-advised (*e.g.*, eradication of acridids) should be excluded on environmental and practical grounds.

Obstacles to Sustainable Acridid Pest Management

Novel solutions for unique problems.— Perhaps the greatest challenge in developing acridid management programs is overcoming the tendency to extrapolate other pest management systems to grasshoppers and locusts. These insects are profoundly and qualitatively different than other pests, and efforts to simply overlay other practices and approaches are likely to fail. The most important features making acridid pest management unique include: discontinuity and severity of infestations (the outbreaks of acridids are sporadic but agricultural losses can be total), simultaneous geographic

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extent (outbreaks and plagues can cover immense territories but agricultural losses are localized), cultural/political context (acridid outbreaks typically receive much greater public attention than other pest infestations), geopolitical difficulty (outbreaks of acridids, and especially locusts, often occur in remote areas that are sometimes inaccessible because of armed conflict), damage complexity (numerous, nonmonetary externalities arise during outbreaks and management efforts), and biological intricacy [population dynamics conform to complex, nonlinear mathematical models (Lockwood & Lockwood 1991, 1997) and features such as phase transformation in locusts confound applications of standard equations that treat a species as a homogenous entity].

A moving target.— One of the most important impediments to sustaining systems for the management of grasshopper and locust infestations is the erratic nature of the population dynamics. As such, maintaining a survey and suppression infrastructure during periods of recession has proven to be a difficult challenge. Attempting to impose a continuous investment of resources into a problem that is inherently discontinuous invites failure. To sustain an acridid pest management system would seem to require strategies for both multitasking and preventative management. Multitasking means the involvement of individuals in several related tasks of pest management (*e.g.*, in Wyoming, the weed and pest district staffs devote their time to weed management, which is a continuous problem, so that an infrastructure is in place when grasshopper outbreaks develop). A shift to preventative management would focus on monitoring, an ongoing task that is fundamental to the prevention of outbreaks or plagues. In the case of desert locusts, survey scouts could also be engaged in routine rangeland survey for livestock production and extension of crop management information to local people. This approach would require a smaller but more stable infrastructure, as compared to the boom-or-bust allocation of resources that emerges from reactive control programs or a unit dedicated solely to acridid survey and control.

Government dependency.— Another significant obstacle to sustainable pest management is the historical dependence on distant governments. National governments often have the resources, knowledge and expertise that is required, and a sufficient investment in transferring the responsibility to more local agents has not been forthcoming. Hence, local agriculture is expected to carry the burden without adequate preparation or training. The legacy of national and international agencies is to have exchanged, at least to some degree, "local needs ... for cosmopolitan wishes" (Sturt 1980) or, in the case of acridid pest management, perhaps we have traded local wisdom for global knowledge. That is, site-specific opportunities and indigenous relationships have been replaced by standardized programs using generalized methods. When these externally developed systems have been withdrawn, there arises a vacuum of pest management capacity.

Mismatched scales.— The difficulty with involving diverse interests in acridid pest management — especially the enormous range of geopolitical, social, interest, and temporal scales that have developed – is the inherent mismatch of perceptions of scales used by the various stakeholders. For example, funds are exchanged for materials (a farmer-rancher may buy insecticide), political allegiance (a government may provide money to another country in hope of currying favor), and amenity value (a public may provide money to foster a sense of pleasure that comes with helping the less fortunate). In the end, only the farmer or rancher has nothing to gain in absolute terms from the acridid outbreak, and the gains of the other parties range from money to pleasure. Developing a market for such diverse exchanges is a challenging task, particularly when the rate of exchange between currencies (*e.g.*, money for political allegiance) is subject to rapid and unpredictable fluctuations.

The obstacle of mismatched scales cannot be overestimated. The damage of acridids is often localized and intense, but the scope of interventions is usually diffuse and shared. This situation arises largely as a function of the fact that the harm is clearly concentrated at the level of the individual farm or ranch, while the spatial scale over which these discrete foci of destruction occur is frequently vast. Moreover, the temporal scale of the damage is far more compressed than that of the interventions. Hence, a sustainable and effective acridid pest management system must be scaled to meet the spatial and temporal contexts of the agriculturalist. Although collectivization may well emerge as part of the solution from a bottom-up conceptualization of the problem, to be sustainable the resulting centralized organizations must ultimately serve the next level down – not the next higher level of bureaucracy.

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