Invasive Species and Common property: The case of bracken fern (*Pteridium aquilinum* (L.) Kuhn) invasion in the region of Calakmul

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Abstract

Plant invasions, affecting ecosystem recovery and household economics, are an important part of land-use change in the Calakmul region, Mexico, closely related to ecosystem function and homogenization of landscapes. Bracken fern has increased four-fold in the area since 1985, impeding regular succession of the vegetation and affecting the amount of areas under forest opened for cultivation. The general assumption drawn from the literature links this invasion to land degradation, but the spatial distribution of bracken fern and its relation with land-use suggests a more complex process involving land-use strategies, land degradation, and fire regimes.

The distribution of bracken fern in the region is characterized by low density of bracken in land-sparse areas where intensive cultivation is predominant (swidden cultivation coupled with commercial chili production), and a high density in land-surplus areas characterized by less intensive cultivation (former large-scale agricultural and cattle projects). For the most part, cooperative projects clearing large amounts of continuous terrain have taken place in the older and larger *ejidos* in which households have up to 100 ha in usufruct land. In such land surplus conditions, there is little incentive to combat bracken fern on non-household land or to invest the scale of labor needed on household lands, given other, viable options. Alternatively, where land is scarce and the household economy dependent largely on cultivation, the fern is attacked through labor.

These circumstances and responses are consistent with small-holder behavior among "hybrid" (subsistence and market) producers. Bracken fern can be seen as a perturbation, similar to drought, to which farmers must decide if and how to allocate their labor and capital. The

apparent rewards to combating bracken fern, given its high labor costs, are low compared to off-farm and NGO- and state-sponsored and state-subsidized activities. Where the latter are a significant option and land pressures are low, the investment is not made. In contrast, where commercial chili cultivation is important and land pressures are high, the investment is made. The labor invested does not intensify cultivation as much as it helps to alleviate a perturbation on production or loss of land.

Introduction

Research on plant invasions is growing mostly within the ecological community. It has so far centered on how plant invasion affects ecosystem structure, environmental productivity, biotic diversity, and other factors related to ecosystem function in the face of land-cover change (Elton, 1958; Hobbs, 2000; Mooney and Hobbs, 2000; Lodge, 1993; Sutherst, 2000; Vitousek, 1994; Vitousek et al., 1997). While ecological research recognizes the human-environment relationships embedded in plant invasions, most attention until now has focused on the ecological consequences (Hobbs, 2000). Much less attention has been given to assessments focused on human-environment interactions per se, in which the biological nature of invasions is explicitly linked to social, economic, and cultural causes of land transformation (Robbins, 2001).

The relation between human activities and the presence of invasive species is complex (Hobbs, 2000). Disturbances are part of ecosystem dynamics; nevertheless, human alteration of such disturbance regimes results in the introduction of novel disturbances that produce changes in the system settings (e.g. resource availability), and that more often increase the opportunities for invasion (Vitousek et al, 1997). Land-use change has clearly exacerbated the adverse effects of invasive species on native biodiversity by creating suitable habitats for such species, from which they can either permanently or temporarily invade remaining indigenous habitats. Cases where human activities actually restrain such processes of invasion are not very well documented, however. The process of bracken fern invasion in the southern Yucatán provides a good example in which human activities not only promote, but also restrain its dispersion.

Plant invasions, affecting ecosystem recovery and household economics, are an important part of land-use change in the region, closely related to ecosystem function and landscapes (Schneider, 2004). Bracken fern has increased four-fold in the area since 1985, associated directly with human disturbance, primarily agricultural activities. Once established, bracken fern's

persistence is supported by fire, mostly incidental burns from the large amount of swidden fires set every year to clear farm and pasture lands. Its impacts include impediment of forest succession and farmland fallow, reduction in biotic diversity, and high labor costs to combat its spread. The general assumption drawn from the literature links this invasion to land degradation (Suazo, 1998), but the spatial distribution of bracken fern and its relation with land use suggests a more complex process involving land-use strategies, land degradation, and fire regimes. This paper centers on explaining the relations of land management practices and current distribution of bracken fern in the Calakmul region. First, a description of the ecology of bracken fern is presented, followed by a characterization of the study region.

Formatte

I. Bracken fern (Pteridium aquilinum (L.) Kuhn)

Bracken fern is considered one of the most successful plant invasive species in the world (Taylor, 1990). A widely distributed vascular plant, it occurs in all but desert and extremely cold regions of the world. It occurs in various types of habitats, from woodlands to grasslands, and, once it is established, it becomes a troublesome weed difficult to eradicate because of its persistent underground rhizome (Fletcher and Kirkwood, 1979). It establishes itself on areas dominated by fires, deforestation, and agricultural activities (Page, 1986), causing severe problems to both farmers and conservationists (Pakeman et al., 1994). The main strategies for bracken to arise and succeed are: high resistance to diseases and pests (Cooper-Driver, 1990), the presence of allelopathic substances (Gliessman and Muller, 1976), vegetative reproduction (Page, 1986), the high density of the frond canopy and litter suppressing of the ground flora, and tolerance to a broad range of climatic and edaphic conditions (Page, 1986: Gliessman and Muller, 1976). Another factor contributing to bracken fern invasion is the resistance of the rhizome to fire and adverse weather conditions, allowing the colony to spread vegetatively (Fletcher and Kirkwood, 1979).

Larger homogeneous areas of bracken are mostly correlated with human activities (Rymer, 1976). Bracken fern is reported as an agricultural weed in Europe, Canada, USA, Australia, and New Zealand; however the dynamics of invasion in tropical landscapes is minimally addressed. The high success of bracken fern invasions in tropical regions is due in part to its dispersion mechanisms. Bracken fern rhizomes run deeply into the soil and are the main factor responsible for colony expansion. Spores are dispersed all through the year and once the individuals are

established, deep rhizomes allow their local persistence. Research on this invasive in Mexico is modest, although its disruption of land uses is well known. For example, in Chiapas, Mexico, bracken fern covers as much as 360 km^2, disrupting both agricultural and cattle ranching activities (Suazo, 1998). It is also a successful invader in the southern Yucatán peninsular region. Characteristics such as resistance to fire, tolerance to long dry periods, low susceptibility to diseases, carcinogenic effects on potential predators (e.g. cattle) and high rates of dispersion, make bracken fern very difficult to eradicate. Bracken fern plots tend to be large (> 0.5 ha) and homogeneous due mainly to a frequent fire regime. Bracken fern rhizomes run deeply into the soil and are the main factor responsible for colony expansion. Areas covered by the fern are, of course, distinctive structurally from forest and other disturbed land covers in the region, which allows the detection, and differentiation in remote sensing analysis (Schneider, 2004).

II. Southern Yucatan and Bracken Fern Invasion

The study region occupies about 22,000 km^2 of southwestern Quintana Roo and southeastern Campeche, north of the Mexican-Guatemalan border (Figure 1). It contains the largest and most rapidly disappearing continuous tract of seasonal tropical forest in Mexico (Peréz-Salicrup, 2004). The region's topography is characterized by undulating uplands interspersed with large solution sinks or *bajos*. The well-drained uplands dominate, ranging from elevation of 100 meters on the eastern and western sides and rising to 350 m in the center of the region. The area is covered throughout by thin rendzinas or mollisols. *Bajos* hold water during the wet season, fostered by the buildup of vertisols of thick clay. A significant difference in total annual rainfall is observed from the southeast to the northwest, ranging from ~ 1,400 mm to ~ 900 mm. A seasonal deciduous forest covers the region with two main types: upland forest (*selva mediana*) and wetland forest (*selva baja inundable* or *bajo*).

The region was the northern part of the central lowlands of the Classic Maya civilization, and experienced one long wave in the rise and decline of occupation and use associated with that civilization until about A.D. 1000 (Turner, 1983; Turner et al., 2004). The forest returned, although altered in species composition, and remained largely unpopulated until recently. The region was significantly logged of its hardwoods (Spanish cedar and mahogany) in the mid-1900s, followed by extensive colonization from various parts in Mexico. With an increase of the population from 2,500 to approximately 35,000 between 1960 and today, the southern Yucatán

peninsular region finds itself in a human-use struggle to find a balance between the agricultural needs of the new settlements and broader aims to preserve the region as a biotic reserve and biological corridor (Klepeis, 2001; Turner et al., 2001).

The dominant land tenure system in the region is the *ejido*: communally managed land granted by the Mexican government to farmers. Most agriculture within ejidos is based on swidden techniques with continuous rotation through forest fallow (Klepeis et al. 2004). The agricultural system referred to locally as *milpa*, is dominated by maize but is often intercropped with squash and beans. In recent years, a growing number of farmers have introduced commercial crops, most notably chili and pasture into their land-use portfolios (Keys, 2004). While the incorporation of such uses has increased the complexity and variation of swidden practices, earlier research in the region by Turner (1983) suggests that farmers employed a plot-fallow rotation converting roughly to a 1:3-4 ratio cycles, usually predicated on 3 years of cultivation and 9 to 12 years of fallow. This range is still in practice, except for the impacts of some chili cultivation practices (Klepies et al. 2004; Keys, 2004).

Remote sensing analysis shows that approximately 3.8% of forest (mainly upland growth) was lost from 1987 to 1997 (Roy Chowdhury and Schneider, 2004), but with significant sub-regional variations in amount and rates of loss. The east- and west-central edges of the region have been substantially deforested for the longest period, but the current focus on new deforestation is along the southeastern edge of the Calakmul Biosphere Reserve. Overall, the focus of cultivated lands appears to be shifting to successional forests, indicating a shortening of fallow cycles (Roy Chowdhury and Schneider, 2004). Significantly, much of this shift is linked to the emergence of market jalapeño (chili) production, as it is woven into milpa or undertaken through more permanent kinds of cultivation (Keys, 2004). These and other land pressures pose various problems in concert with the needs of the conservation and archeo-tourism programs for maintenance of mature forest in the region and for lessened demands on remaining forest on ejido lands (Primack et al., 1998; Turner et al., 2004).

II. Regional Patterns of Bracken Fern and their Land Management Linkages

Analysis of remote-sensed imagery-based data for the last 15 years reveals the recente increase, extent and regional distribution of bracken fern (Schneider, 2004). The results of such analysis are assessed with regard to prevalent land tenure and land use, the size and age of the *ejidos*, and

ejido distribution in the region. At least four types of land tenure exist in the region: *ejido* land (largely usufruct), private land (largely ranches), forest extensions (*ampliaciones*) and National Land, the latter assigned exclusively to the Calakmul Biosphere Reserve (Fig. 1). Figure 2 shows the relative density of bracken fern and its increase in the last 15 years in each of the main land tenure regimes in the region. Private lands have the highest density and largest increase, followed by *ejido* land; bracken fern is almost absent in forest extensions and in the Calakmul Biosphere Reserve. This result is expected because the invasive species requires disturbance to establish itself and the major human disturbance on the landscape has taken place in *ejidos* and on ranches. Private ranchers clear considerable land but do not necessarily invest the labor to keep up the pasture that they have created. In turn, the opened areas are ready for bracken fern to invade, which is then promoted by intended burning to combat brush and incidental burns from *milpa* fires that usually burn around the ranches.

The extent and density of bracken in the *ejidos* imply a more complex relation involving size and distribution of the *ejidos*. The general trend is that the larger the *ejido*, the larger the amount of land under bracken fern invasion. Of 115 agricultural *ejidos* in the study region, more than half (72), mostly in the western and northern parts of the region, are covered with less than 1 km^2 of bracken fern, 36 *ejidos* have between 1 and 5 km^2, and 7 have more than 5 km^2. The last seven *ejidos* contribute 45% of the total cover of bracken fern in the region, and they are located mostly in the eastern part (table 1). The *ejidos* in the state of Quintana Roo have a different land-use history from the rest. They are typically the oldest settled and they provide substantial hectares per *ejidatario*, in some cases averaging more than 100 ha. This part of the region as well appears to be most affected by hurricane blow-down of forest, including the devastating impacts of Hurricane Janet in 1955 (Whigman et al., 2003). Very recently, these *ejidos* appear to be de-emphasizing subsistence cultivation, and shifting mainly to cattle ranching.

It is not clear if there is a positive relation between year of establishment, or the age of the *ejido*, and bracken fern invasion. Older *ejidos* have witnessed 2-3 or more swidden cycles and studies indicate that successional growth on lands experiencing this many cycles may have reduced fertility (Read and Lawrence 2003). If more "exhausted" cropped lands are more prone to fern invasion, a positive relation should exist between the age of the *ejido* and the amount of areas under bracken fern. However, the results in Figure 3 indicate that the amount and density of fern

are independent of the age of the *ejidos*, suggesting that bracken fern is not necessarily related to long periods of disturbance, or resource depletion.

Regional patterns indicate that there is a strong relation between human activities and the area under bracken, as well as the persistence of bracken fern (biophysical factors are indeed critical but are not addressed in this paper). It is important to uncover what kind of land management practices promote or deter the invasion, as well as to understand the effects of the invasion on the livelihoods of local communities. These issues are explored below through a case study of two *ejidos*.

III. *Ejido*-Level Patterns of Bracken Fern

The two *ejidos* examined here were selected using information on fern density derived from 1997 satellite data. A stratified random sample of 46 farmers in the two villages was selected for interview; the interviews were conducted between January and June 2002. The farmers selected for interview are part of the official lists of *ejidatarios*, which were obtained from the chair of the ejido (*Comisario Ejidal*). The lists were then divided between *ejidatarios* with and without fern on their lands, and farmers selected randomly from each category. A standardized questionnaire was administered to the *ejidatarios*; the questionnaire was used to elicit the socio-economic and land-use history. Farmers were asked questions about their immigration history, off-farm employment, the demographic composition of their households, their farm production, inputs, and fallow cycle, and bracken fern issues. In addition, each interview involved a guided tour of the agricultural plots of the respondent. Using a global positioning system (GPS), a geo-referenced sketch map detailing the configuration of the land and its uses was created, permitting linkages to the remotely sensed data and providing the spatial context for the land-use history obtained from the farmers.

Characterization of Ejidos

The two *ejidos* chosen for the detailed study are distinctive not just in terms of their location, area and bracken fern density, but also in terms of their land-use history and current land management practices (see figure 1).

a. La Guadalupe

La Guadalupe has a total area of 50 km^2 with a population of 300. It is located in the southern part of the region, 15 km west of the southern road on the edge of the Calakmul Biosphere

Reserve. The ejido was established in 1984 and the founders were mainly *pobladores* (farmers without land granted to them but who live on the *ejido*) from the neighboring *ejido*, the first to embark on commercial chili production in the region (Keys, 2004). The farmers' basic activity is the *milpa* combined with chili (most of the *ejidatarios* had experience with chili before arriving in the *ejido*), and very few farmers have cattle.

La Guadalupe is one of the most recently established *ejidos* in the area, granted just before the creation of the Calakmul Biosphere Reserve (CBR). At least 20% of the *ejido* falls in the buffer zone of the CBR. A total of 84 *ejidatarios* have land rights with only 40 ha of land assigned to each, a small amount compared to other *ejidos* in the region. Current agriculture focuses on secondary growth vegetation, owing to strong regulations by the CBR forbidding the cutting of more forest; the CBR awards *apoyos* or subsidies to the *ejido* to offset this limitation. Fallow cycles average two consecutive years of cropping per parcel and at least four years of fallow (2:4). Some chili plots are mechanized—prepared by disking with the *Sociedad de Apoyo Rural's* (Society for Rural Development) tractor, which is subsidized by the state.

The area under bracken fern is modest, very recent in its emergence, and located close to the center of the village (fig 4). The average plot area of fern is around 3 ha, smaller than the average *milpa* (agricultural) plot of 5 ha (table 2). The fern plots are usually surrounded by old secondary vegetation or forest, which inhibit the expansion of the species. Only 19% of the *ejidatarios* have bracken fern on their parcels. Deforestation rates in the last 15 years are higher than for the whole region (1.3% compared to 0.3 %); however most of the deforestation had occurred between 1985 and 1996. From 1996 to 2001, areas of secondary growth have been turning into areas for cultivation . Patches of fern bigger than 1 ha are usually abandoned, and farmers avoid burning these patches and the areas surrounding them.

Farmers attempt agriculture on lands invaded by bracken fern due to their soil characteristics, especially after burning. *Ejidatarios* have tried *milpas* and agro-forestry on the areas invaded. To do so requires at least twice as much labor and yields one-third the harvest compared to normal *milpas*. Those farmers willing to undertake the extra labor and lower yields on fern plots are initially attempting to eradicate the invasion and move to a parcel with a better location. Due to the lack of success, they seek external income in order to move to a better parcel. Land pressures in La Guadalupe are sufficiently high to warrant this response as well as management

practices aimed at combating the spread of the fern. In addition to "fire protection", farmers also cut bracken fern when it appears in their fields, attempting to keep it from spreading. Weeding is an important activity during *milpa* cultivation; an interesting result from the study shows that farmers not affected by larger bracken fern areas spend more working days weeding than farmers with areas of bracken.

b. Nicolas Bravo

Nicolas Bravo, is one of the largest *ejidos* in the region and possesses the highest amount of bracken fern: 38 ha (Fig 5, table 3). It is one of the oldest *ejidos*, not only in the region but in the entire country (Klepeis, 2000; *comisario Ejidal personal communication*). It was established as a forestry community with extremely large household holdings and forest set asides. Located on the eastern edge of the study region, its 932 km^2, including 389 km^2 of forest extensions, are in the state of Quintana Roo. It once held the largest wet rice agricultural program in the state, but the *bajo* (wetland forest) area cleared for it is now in pasture for a livestock program. Currently, 9% of the *ejido's* land cover is under agriculture and 22% is covered by secondary growth. The main changes in that part of the region over the last 15 years are the decrease in agricultural land and the increase of bracken fern, such that the fern areas exceed cultivated areas. Bracken fern plots are large and conspicuous; their average size is 19 ha, and 46% of *ejidatarios* are affected by the invasion (Table 3). Nicolas Bravo reports the highest area cleared for agriculture between 1930-1960: 4,500 ha—twice as much compared to any *ejido* in the region, such as the larger *ejidos* in west Silvituc: 2,655 ha. (Klepeis, 2000).

Nicolas Bravo rests within the center of the pathway of the 1955 Hurricane Janet, which devastated much of the forest lands (Whigman et al., 2003). Many trees were blown down in major swaths following highway 186 to the west. The dead biomass promoted one of the largest fires reported in the region. (Most farmers interviewed reported these fires as the most extreme that they ever experienced.) These fires opened large areas for potential bracken invasion, although confirmation that bracken problems began at this time does not yet exist. Accounting for the subsequent large-scale projects there, approximately 50 % of the *ejido* area outside of the forest extension areas has been disturbed, a high percentage compared to the previous *ejidos* where the values range from 20% to 30%. Deforestation rate between 1985 and 2001 is low, an annual rate of 0.1% annually below the regional deforestation rate, showing that in the last 15 years mostly secondary areas have been used for agriculture.

A program of large-scale agriculture, Plan de Desmonte Nacional (National Deforestation Plan), was promoted during the presidency of Luis Echeverria (1970-76). Its goal was to promote large-scale agriculture in order to increase crop production and farmers' income. Nicolas Bravo's landscape was highly influenced by this and subsequent programs. Farmers initially cleared up to 300 ha for maize and reported up to 4 tons/ha of maize, compared to the average good yield of 1 ton/ha. These areas shifted quickly to cattle ranching projects, mostly managed by *ejido* members who thought the venture would be more profitable than cultivation. Some of the ranching projects ended due to the end of subsidies and internal management conflicts.

Former cattle ranch projects sponsored by a municipal-level, government program to assist *ejidatarios* or farmers present a clear example of the implications of land clearing on bracken fern invasion. Beginning in the early 1980s, farmers cleared approximately 200 ha used for maize mixed with pasture. After two years the land was cleared and covered fully with pasture grasses. The project persisted until 1987 when it ended due mainly to internal conflicts among its members. Cattle was sold and the land was abandoned; abandoned plots were invaded by bracken fern. Opened but unmanaged land provides an ideal condition for bracken fern—minimal competition for light and dry vegetation receptive to incidental burning from swidden fires surrounding the abandoned ranch. In this case, the invaded lands were under no specific farmer's control and were of no value to any individual household. Therefore, no one attempted to combat the fern. Firmly established, the fern's fire ecology insures its persistence in the near term. Indeed, some bracken fern stands in the region have existed for more than 25 years, and not necessarily on abandoned, large-scale projects. Much individually controlled farm land has long been invaded and the fern has persisted, in part because the size of the areas invaded are too large to warrant the labor necessary to combat it, given the amount of lands controlled per household and the diversification of activities in the *ejido*.

In summary, this old *ejido* has *ejidatarios* with land surplus as well as various past large-scale production experiments in which no individual household controls the abandoned lands. Bracken fern has invaded these commons and many farm plots, persisting for several decades. The reduction of *milpa* importance, apparently linked to agricultural subsidies (e.g PROCAMPO's payments) and the increase in off-farm income, helps to accentuate the fern by de-emphasizing the need for farm land.

c. Comparison between the ejidos

The land-use history and current land conditions of these two case-study *ejidos* are contrasting. La Guadalupe, a relatively new *ejido* characterized by high land pressures, strong involvement in cropping, has the highest percentage of forest and lowest percentage of bracken fern areas. Nicolas Bravo, the oldest *ejido* characterized by low land pressures and a more recently disinvestment in cropping , has the highest percentage of bracken fern invasion.

Virtually no difference exists between the *ejidos* with regard to how *milpas* are cultivated use of areas under old secondary vegetation is preferred, and areas are burned before planting and weeding, at least once during the season. La Guadalupe however shows the highest level of farmers involved in *milpa*. The fallow cycles are slightly higher in La Guadalupe. Keys (2004) reports that chili and *milpa* are commonly conflated in the *zonas chileras*, where La Guadalupe resides. Farmers interviewed in the fern study, however, implied that their chili parcels were separate (presumably the intensive or mechanized chili lands) from their *milpa* parcels. Fallow cycles varies only slightly from the land-rich Nicolas Bravo farmers to the land-stressed La Guadalupe farmers --2 years cultivation, 5 years fallow in average, much shorter cycle than the one reported by other for the region (Klepeis et al., 2004).

Land-use histories and the significance of cultivation to total household income do seem to be important with regard to bracken fern distinctions. Nicolas Bravo is one of the oldest settlements in the eastern part of the region and has experienced a variety of programs that fostered the opening of large areas of land, either for cultivation or cattle. In either case, the land that has been open and not kept for either practice (cattle/agriculture) had facilitated the invasion by bracken fern. The size of land holdings in Nicolas Bravo (low land pressures) apparently promoted a similar response on household controlled lands. Large parcels invaded by the fern have been largely abandoned; over time, off-farm and other external income activities have increased in this area. The fact that *ejidatarios* tend to plant *milpas* in proportion to their PROCAMPO payments supports the declining role of maize cultivation there. La Guadalupe's economy is devoted to cultivation; most of the farmer's main sources of income are related to cultivation. Under high land pressures then the farmers control the spread of bracken fern.

In each *ejido*, invaded parcels have been explored in terms of maize cultivation. Various farmers claimed that by engaging high labor costs by weeding the fern three or four times during the

cropping cycle, they could generate reasonable yields. Interestingly, however, the reported overall yields on bracken fern parcels are significantly lower than on "normal" lands, and all farmers reported abandoning bracken-parcel *milpas* after two years of cultivation and not returning to them. This strategy may reflect the high labor costs involved in the cultivation and lower yields.

Observations hint that well kept pasture land resists bracken fern invasion, although some of the largest areas invaded are abandoned ranch lands, presumably triggered by incidental burning. Combating bracken fern appears to be the same everywhere. It involves cutting the fern as it appears in a plot, which is usually done during weeding. Once the other vegetation reaches a sufficient height and density, its shade tends to retard the fern's growth and expansion. The species grows so rapidly, however, that several weedings must be undertaken before crops or bushy vegetation can create sufficient shade as well as to avoid fires, which are promoted by the large amount of dry biomass created by the fern. Respondents note that controlling fire (reducing incidental burning) and maintaining forest edges also helps to control the fern. Crown shade on edges tends to reduce the fern permitting regeneration of other species and the "in-creeping" of forest over time. Recently, some effort has been given to disking and planting large fern areas with pasture grass, on the basis that a thick grass will choke out the fern. It is not yet clear if the labor required to control the fern's regeneration compared to the pasture is worthwhile.

Overall, it would appear that bracken fern has the potential to invade virtually any piece of open land. It tends to become dominant in those cases where large open areas are invaded and, for reasons such as high labor costs, scarcity of cheap and successful herbicides, local land managers decide not to combat the invasion. The decision to do so, thus reducing the density of fern, appears to be related to ejidos and households that have high land pressures and it relies primarily on cultivation for subsistence and income generation.

IV. Conclusions

Regional results indicate a strong relation between the scale and kind of human activity and the presence and dominance of bracken fern. For the most part, larger and older *ejidos* contain more and greater proportions of fern-dominated land.

Disregarding potential biophysical explanations for the presence and spread of bracken fern, the land-use analysis presented here indicates the following: bracken fern easily spreads across the landscape, especially as pathways are opened by land clearance and forest fragmentation. It typically appears immediately after burns. Unless farmers attack it during its initial invasion stage, bracken fern will dominate the parcel in question. Its dominance appears to be related to large-sized parcels that are regularly burned. Large size reflects land abundance, tenure, and household economics, more so than the physical qualities of space occupied. For the most part, cooperative and communal projects clearing large amounts of continuous terrain have taken place in the older and larger ejidos in which households have up to 100 ha in usufruct land. In such land surplus conditions, there is little incentive to combat bracken fern on non-household land or even to invest the scale of labor needed on household lands, given other, viable options for production. Alternatively, where land is scarce and the household economy dependent largely on cultivation, the fern is attacked through labor.

These circumstances and responses are consistent with small-holder behavior among "hybrid" (subsistence and market) producers. Bracken fern can be seen as a perturbation, similar to drought, to which farmers must decide if and how to allocate their labor and capital. The apparent rewards to combating bracken fern, given its high labor costs, are low compared to off-farm employment and NGO- and state-sponsored or state-subsidized activities. Where the latter are a significant option and land pressures are low, farmers do not invest in the control of bracken fern invasion. In contrast, where commercial chili cultivation is important and land pressures are high, the investment is made. This pattern of responses is consistent with induced intensification themes (Turner and Ali, 1996; Laney, 2002). In this case, the labor invested does not intensify cultivation as much as it helps to alleviate a perturbation to production or loss of land.

Bracken fern invasion is partly the result of agricultural practices, such as land clearing and burning. Yet, bracken fern invasion is not just a linear process driven by land management. The

invasion also shapes *ejidatarios'* decisions; the existence of areas of bracken fern in particular configurations has prompted communities of farmers to organize the landscape around decisions they make in combating the spread of the invasive.

Acknowledgements

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V. Figures and Tables

Figure 1. Land grants to *ejidos* and private holdings in the southern Yucatan region (adapted from Klepeis, 2000)

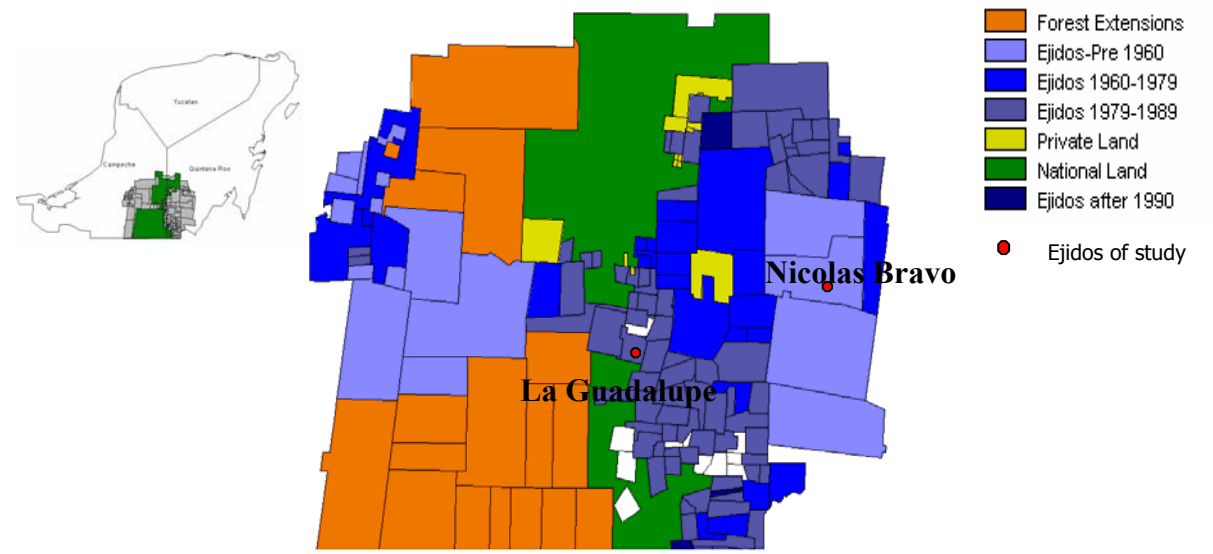

Figure 2. Amount of Bracken Fern by land tenure in southern Yucatan peninsular region

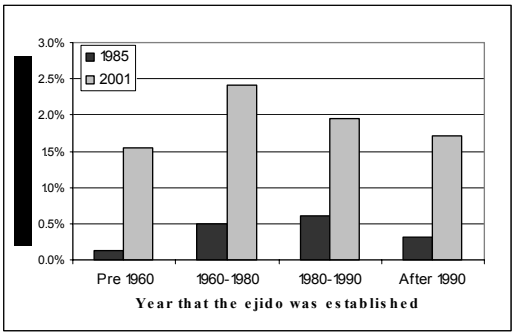

Figure 3. Density of bracken fern from 1985 to 2001 distributed by time *ejdos* were founded.

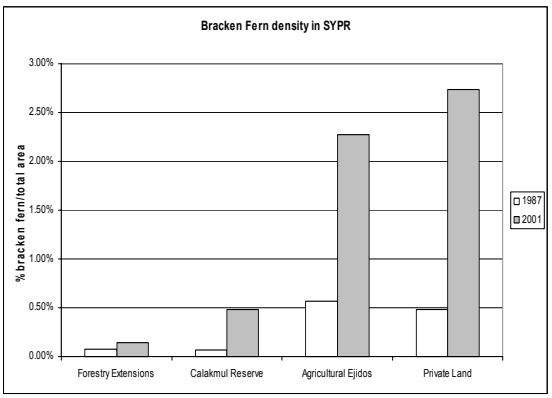

Figure 4. Map of land cover of the ejido La Guadalupe in 2001 in the region of Calakmul

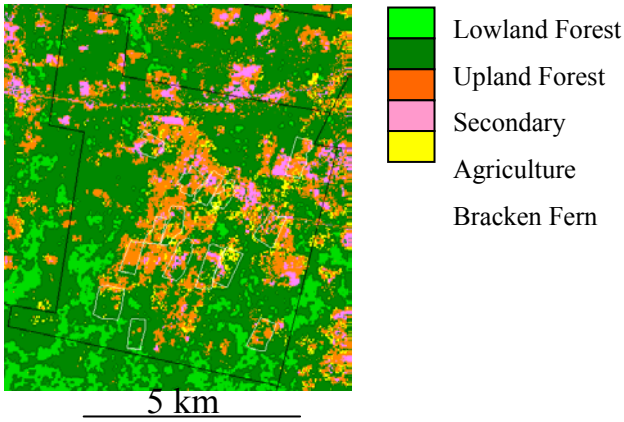

Figure 5. Map of Land Cover in the Ejido Nicolas Bravo in 2001-state of Quintana Roo.

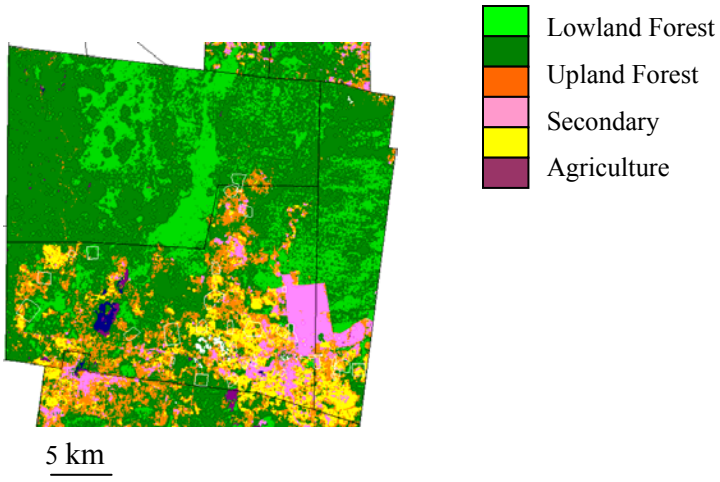

Table 1. Areas of bracken distributed by total area of the ejido in the region of Calakmul.

Area of the *ejido*	**Total number of *ejidos***	**Total area (km^2)**	**Total area under bracken fern (km^2)**	**Average density of bracken fern**
Up to 50 km^2	76 (2 QR*)	2026	57	2.60%
50-150 km^2	25 (2 QR)	2056	54	2.77%
more than 150 km^2	14 (5 QR)	5181	98	2.12%

*Number of ejidos in the state of Quintana Roo

Table 2. Description of the Ejidos La Guadalupe and Nicolas Bravo in the region of Calakmul

	Nicolas Bravo	**La Guadalupe**
Area total of *ejido* (km^2)	932	54
Area total of bracken fern in 2001 (km^2)	38	1.9
Area in forest extensions (km^2)[1]	389	0
Land allocated per *ejidatario* (ha)	100	40
Total population	3,668	311
Number of *ejidatarios*	464	84
Percentage of *ejidatarios* affected by bracken fern	46%	19%
Number people interviewed	31	15

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