Final report on the Joint Fire Science Project 01-1-3-37: Landscape fragmentation and forest fuel accumulation: Effects of fragment size, age, and climate**.**

Project Location: Puerto Rico, Washington, Idaho, Alaska, Minnesota

Principal Investigators: William Gould[1], Grizelle González[1], and Andrew Hudak[2]

1. USDA Forest Service, International Institute of Tropical Forestry, Río Piedras, PR

2. USDA Forest Service, Mountain Research Station, Moscow, ID

Contact Information: W. Gould: 787-766-5335 x302, wgould@fs.fed.us.

This report includes an overview of the research objectives, a statement on how the deliverables listed in the proposal match what has been produced to date, those that are in progress, a copy of deliverables, and a summary of methods, what we have learned, and a list presentations and pending publications derived from this project.

Project overview: Landscape fragmentation can affect fuel accumulation, increase the spatial variability of fuel loads, and affect the susceptibility of forests to fire. Fragmentation creates a complex environment in which to manage forests in the United States and Puerto Rico and few studies have related the combined effects of fragmentation, fragment size, forest type, and climate on biomass, downed woody debris, and decomposition. Our goal is to understand the variability in fuels and forest structure that is created by forest edges and fragmentation. This study has led to information that will lead to better prediction and mapping of fuel loads and fire behavior in fragmented forests and aid in management decisions on public forested lands in Puerto Rico, Idaho, Washington, Minnesota, and Alaska.

We have been investigating the effect of forest fragmentation on fine woody debris, coarse woody debris, standing dead and live biomass accumulation, forest composition and structural attributes, and woody decomposition rates along gradients of climate, stand age, and fragment size by sampling these attributes along transects running from fragment edge to interior in fragments of different sizes (*e.g.* ha to km^2), ages (*e.g.* open young secondary to older closed forests), and in different climates (*e.g.* tropical, temperate, and boreal).

This project has three components: 1. Characterization of differences in forest fragment edges *vs.* interiors in a number of forest structural attributes through field sampling and analysis, 2. Characterization of the differences in forest fragment edges *vs.* interiors in terms of decay rates of wood stakes, and 3. Incorporation of fragment characteristics based on field measured relationships into mapping and analyses of spatial distribution of fuels.

We hypothesized that the rates of productivity, mortality, and decay might be different in fragment edges *vs.* interiors and might be affected by fragment size and structure (open *vs.* closed), and that these effects would vary with climate. We hypothesized that the edge effect would be more pronounced where the edge environment was most different from the edge interior, *i.e.* closed *vs.* open forests, larger *vs.* smaller fragments, and moderate *vs.* extreme climates.

Deliverables: Deliverables outlined in our proposal include the preparation of peer reviewed publications to address 1) fragmentation and fuel accumulation patterns at three scales: fragment, landscape, and regional, 2) the effects of fragmentation on fuel accumulation along climatic gradients, 3) the mechanisms controlling fuel accumulation in tropic, temperate, and boreal forests, 4) methods for assessing and mapping fuel loads in fragmented forests, and 5) fuels maps for the study areas. Technical reports will be prepared addressing 1) remote sensing data acquisition and analyses for landscape fragment analyses, and 2) methods for spatial prediction of fuel loads based on forest type and the degree of forest fragmentation. Workshops will be conducted in to disseminate to land managers and interested scientists information on methods for measuring and mapping fuel loads in fragmented forest ecosystems.

The primary deliverables are the ten in progress publications listed below and referred to in the summary. In addition we have conducted two workshops on landscape fragmentation in Moscow, Idaho and in Río Piedras, Puerto Rico, and participated in the Caribbean Foresters workshop focused on wildland fire issues. We have presented eight talks and posters at scientific meetings. We have produced an initial wildland fuels map of Puerto Rico.

Methods: We measured coarse and fine woody debris, species composition, tree heights, diameters, crown dimensions, duff an litter depths, percent herbaceous cover, percents understory and canopy cover, and tree species composition along 60 m transects crossing 640 fragment edges and interiors in Puerto Rico, Washington, Idaho, Alaska, and Minnesota. Each of these transects consists of 5 sets of plot data at 0, 10, 20, 40, and 60 meters along the transect, with the forest boundary between 0 and 10 meters (Fig. 1). We used Landsat imagery, air photos, and field reconnaissance to locate suitable fragments and transects. Tropical moist and dry forest fragments were selected from a classified Landsat ETM+ image of Puerto Rico modified from Helmer *et al.* (2003) to indicate open and closed lowland moist and dry forest types (Fig. 2). These fragments were stratified by fragment size, with small fragments being less than 9 ha, medium-sized fragments 9 – 36 ha, and large fragments greater than 36 ha (Fig. 3). Temperate moist and dry forest fragments were located in northern Idaho and southern Idaho and Washington (Fig. 4). Boreal sites included Northern Minnesota as our boreal moist climate and interior Alaska as our boreal dry climate (Fig. 5). Transects were located at accessible sites on these fragments and field characterization and aerial photography were used to confirm fragment forest type and size categories.

Coarse woody debris (CWD) and fine woody debris (FWD) in three classes were measured using a line intercept method (Harmon and Sexton 1996), and CDW and FWD biomass estimates were combined to determine DWD estimates in Mg/ha. Coarse woody debris was measured along 30 m transects and CWD diameters were measured and decay class estimated as CWD intersected the transect. Volume to mass conversions used values from Harmon and Sexton (1996) for “unknown decay resistant species” for decay classes 1-5. A total of 96 km were sampled for CWD. Fine woody debris was sampled in 3 classes: FWD1 - 0.25 to 0.6 cm, FWD2 - 0.61 to 2.5 cm, and FWD3 - 2.51 to 7.6 cm. These were tallied as they intersected transects of 3 m, 3 m, and 6 m respectively per plot (Fig. 1). Tallies of FWD were converted to biomass following Harmon and Sexton (1996).

Live tree basal area was sampled using a variable plot with a basal area factor prism and sampled trees were measured for D_{BH}, height, height to the crown, and crown diameter. Each plot was characterized in terms of percent canopy cover, percent woody understory cover, percent herbaceous cover, percent litter cover, percent bare ground, canopy height, understory height, herbaceous layer height, litter layer depth, organic layer depth, and soil temperature at 10 cm depth. Plot attributes measured include the location along the transect, slope and aspect of the plot and transect attributes measured include the location, slope, orientation, and forest fragment type (large, intermediate, or small, open *vs.* closed, moist *vs.* dry).

We conducted a wood stake decomposition experiment on a subset (108) of these transects with the placement of a set of 14 weighed and tagged aspen stakes at 3 positions along each transect: Outside, edge, and interior (4536 stakes). These were collected at 6 to12 month intervals and measured for mass loss and changes in chemistry. Initial findings indicate the highest rates of wood decay are in Puerto Rico are related to both climate and insect (termite) activity. We extracted insects from all wood stake samples collected to date in order to better understand the role of climate and insects in wood decay and the relationship of these effects to fragment edges.

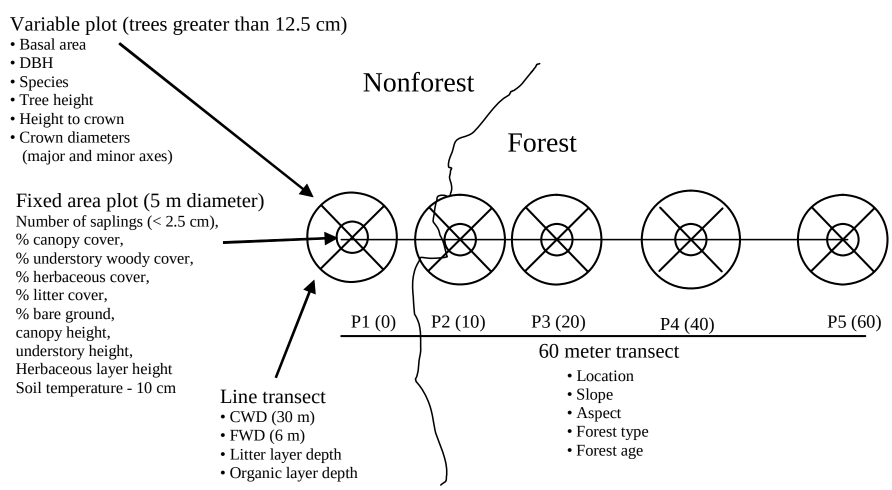

Figure 1. Sampling scheme along transects crossing forest/nonforest boundaries in fragments of various size, climate, and structure categories.

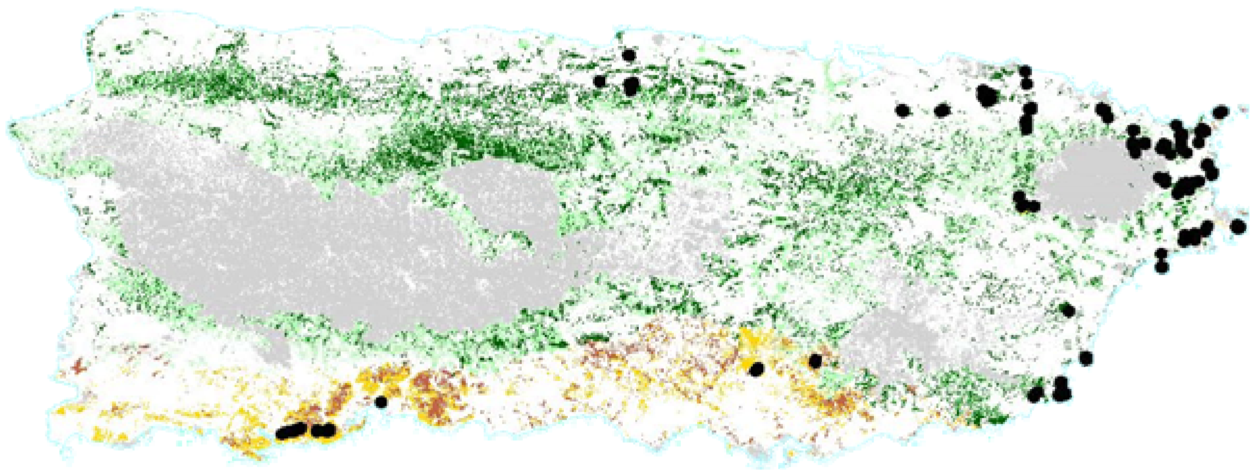

Figure 2. Transect locations Puerto Rico in open and closed lowland moist forest fragments (light and dark green respectively). and open and closed dry forest fragments (yellow and brown respectively).

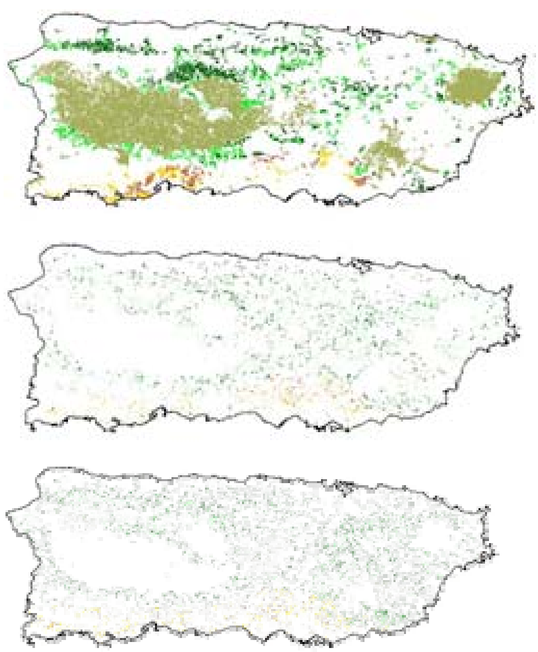

Figure 3. Open and closed lowland moist and dry forest fragments larger than 36 hectares (770 individual fragments, upper map), between 9 and 36 hectares (2746 individual fragments, center map), and less than 9 hectares (29825 individual fragments, lower map).

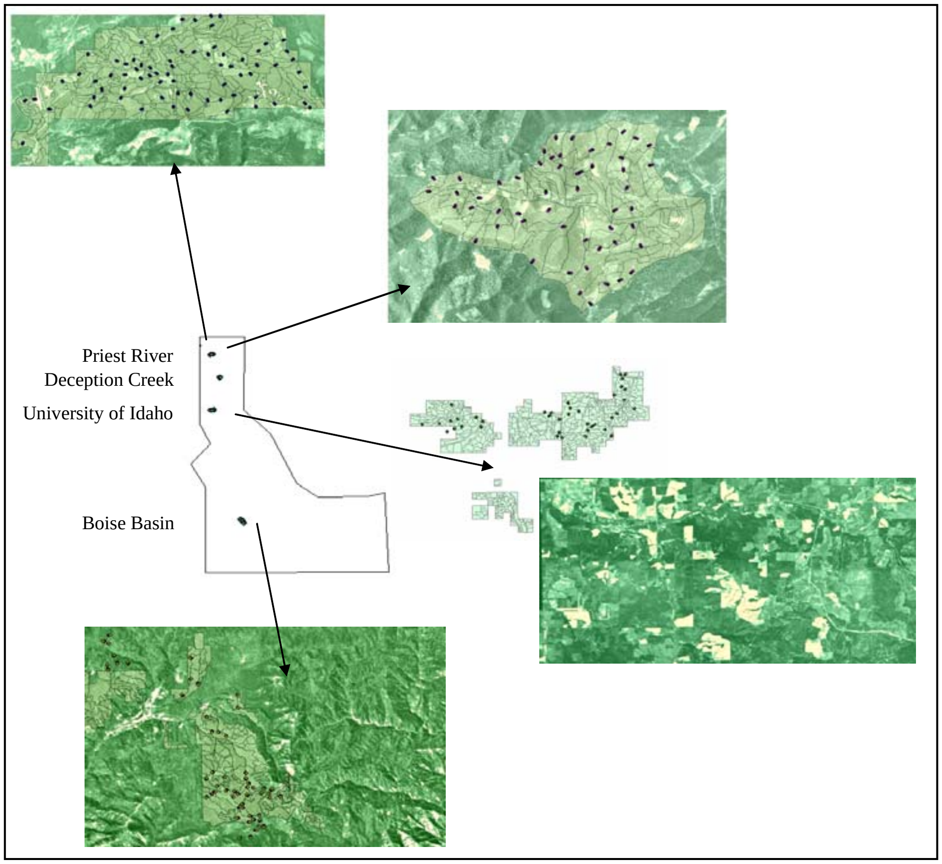

Figure 4. Location of temperate sites.

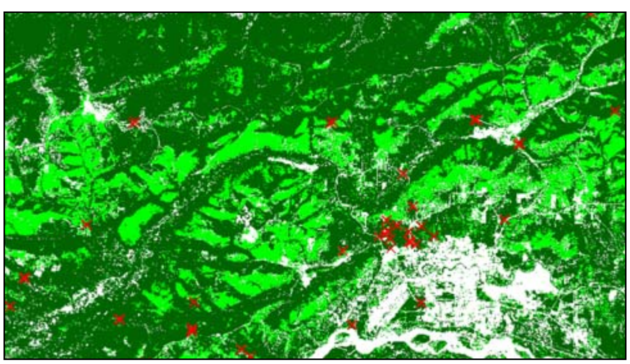

Figure 5. Location of dry boreal sites in the Fairbanks area of interior Alaska.

Summary of findings: Fragmentation varied from forest patches in a matrix of nonforested land to a matrix of forest fragmented by nonforest patches, roads, or other (mss. **1, 5**). Significant edge effects were measured in some forest and fragment types and not in others. Edges differed from interiors in complex ways that varied along the climatic gradient (mss. **4, 10**). Significant differences were found in the live and dead components of the fragments and in the relative amounts of downed and standing dead wood. Boreal and temperate forest fragments had higher live biomass in the edges *vs.* interiors (Fig. 6a). Downed woody debris accumulation was greater in temperate forests with mean plot DWD values 71.1 Mg/ha, and lower in boreal and tropic climates, with mean plot values of 12.1 and 8.8 Mg/ha downed woody debris in boreal and tropical plots respectively. The partitioning of fine and coarse downed wood and snags indicate a higher percent of fine woody debris in tropical sites (Fig. 6b). Boreal sites had greater amounts of dead wood on edges *vs.* interiors and temperate and tropical forests indicate opposite trends (Fig. 6c).

Mean downed woody debris for all tropical sites was 8.8 Mg/ha. Mean DWD was significantly different between open and closed forests, with mean DWD of 9.5 Mg/ha in closed forests and 7.1 Mg/ha in open forests (Fig 7a). Mean DWD was significantly different ($p < 0.05$ in all cases) between forest moisture classes, with 10.8 Mg/ha DWD in moist forest and 5.7 Mg/ha DWD in dry forests (Fig. 7b). Mean DWD was significantly different at the 90% confidence interval by forest size class with mean DWD of 9.6, 8.0, and 7.1 Mg/ha respectively in large (> 36 ha) medium 9-36 ha) and small 1-9ha fragments (Fig. 7c). Mean DWD was significantly lower outside the fragment edge but not significantly lower between edge and center positions with a trend to higher DWD in fragment interiors (Fig. 7d) (mss. **3, 7**).

The decomposition experiment is still ongoing and initial findings indicate the decay rate in the tropical fragments to be an order of magnitude greater than in the temperate of boreal fragments. Decay rates in the tropical fragments were greater than might be predicted by climate alone due to the presence and abundance of termites. Analyses of the variation in fragment edge and interiors and of the effects of fragment size and structure are ongoing (**2**).

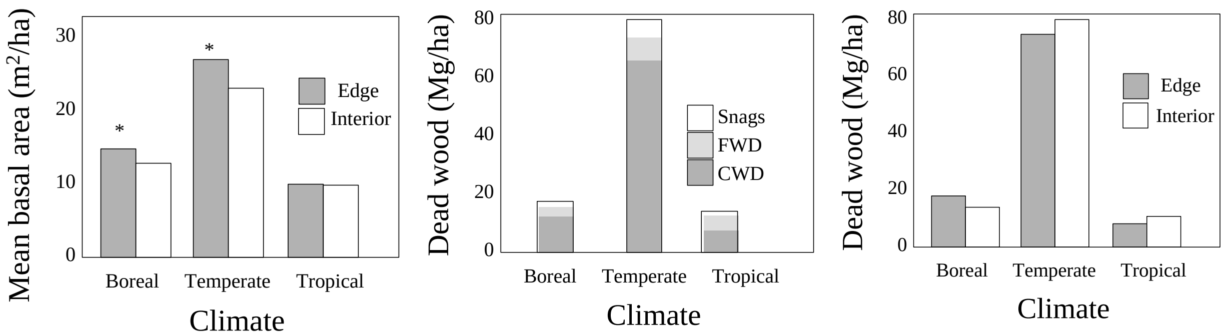

Figure 6. Edge *vs.* interior relationships in boreal, temperate, and tropical fragments. Live biomass is greater in boreal and temperate edges *vs.* interiors (6a). Dead wood accumulation was greatest in temperate fragments and the fine woody debris fraction was relatively greatest in tropical fragments. Dead wood accumulation was higher in boreal edges than interiors and temperate and tropical fragments had higher dead wood accumulation in interiors *vs.* edges.

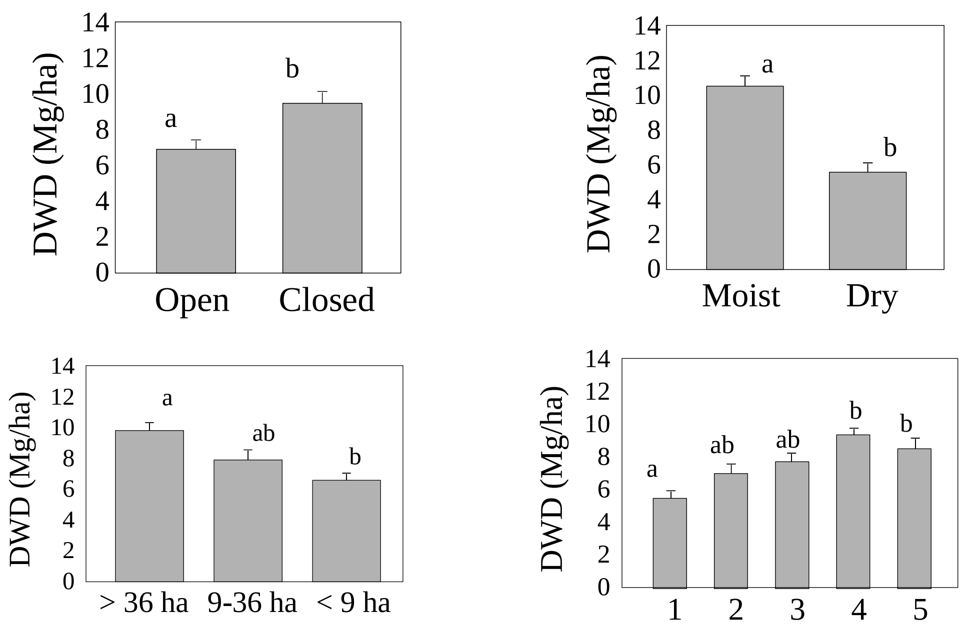

Figure 7a-d. Mean downed woody debris (DWD) per plot in Mg/ha by forest structure *i.e.* open (O) younger forests *vs.* closed (C) older forests in 2A, by forest type *i.e.* moist (M) lowland *vs.* dry (D) forests in 2B, by fragment size *i.e.*, > 36 ha (L), 9-36 ha (M), and 1-9 ha (S) in 2C, and by plot position along the transect *i.e.* 5 m outside the fragment edge (1), 5 m inside the fragment (2), 15 inside the fragment (3), 35 m inside the fragment (4), and 55 m inside the fragment (5). Significant ($p < 0.05$) differences from a univariate analysis of variance (SPSS 2002) are shown in lower case letters.

Empirical DWD values can be used to model carbon storage and fuel loads and extrapolate these based on forest type, structure, and fragment size. The lack of significant edge effect will be further explored but if it holds it indicates that the edge to area ratio of fragments may not be important in extrapolating these measured DWD values. Differences in fuel loads in fragment edges *vs.* interiors has been shown to alter fire behavior in modeling efforts and we are developing fuel maps that can incorporate our field measures of edge effects (mss. **8, 9**). We have developed a map of wildland fuel types for Puerto Rico and will incorporate fuel loads based on modeled effects of fragmentation as these models are developed (ms. **6**).

Presentations and publications

Talks and posters (10)

Gould, W.A., A. Hudak, G. González, and F. Scatena. 2002. Overview: Landscape fragmentation and forest fuel accumulation: Effects of fragment size, age, and climate. First workshop on forest fragmentation and fuel load. March 2002. Moscow, ID.

G. González. 2002. Landscape fragmentation and forest fuel accumulation: effects of fragment size, age and climate – a decomposition experiment. Workshop on forest fragmentation and fuel accumulation. Moscow, Idaho.

Gould, W., A. Hudak, G. González, and T. Hollingsworth. 2003. Landscape fragmentation and forest fuel accumulation. Talk and poster presented at the Joint Fire Science Program annual meeting, February, 2003, Phoenix, AZ.

Gould, W., A. Hudak, and G. González. 2003. Landscape Fragmentation and forest fuel accumulation: Effects of fragment size, age, and climate. Second workshop on forest fragmentation and fuel load. February, Río Piedras, PR.

G. González. 2003. Landscape fragmentation and forest fuel accumulation: effects of fragment size, age and climate – a decomposition experiment. 2nd Workshop on forest fragmentation and fuel accumulation Río Piedras, PR.

Gould W. and G. González. 2004. Effects Of Fragmentation On Composition, Structure, And Woody Debris Accumulation In Lowland Moist And Dry Tropical Forests. *Presented at the UPR Río Piedras Biology Departmental Seminar.* March, 2004.

Gould, W., G. González, A. Hudak, and T. Hollingsworth. 2004. Effects of forest fragmentation on coarse woody debris accumulation. *Presented at the Joint Fire Science Program annual meeting*, April 6, Phoenix, AZ.

Gould, W., G. González, and A. Hudak. 2004. Landscape fragmentation and forest fuel accumulation: Effects of fragment size, forest structure, and climate. *Presented the Caribbean Foresters meeting*, Río Piedras, Puerto Rico, June10, 2004 (invited talk).

W. Gould and G. González. 2004. Forest fragmentation and forest fuel accumulation: Effects of fragment size, forest structure, and climate. Tropical Forestry Congress for the USDA FS Centennial. Caguas, Puerto Rico. August 25, 2004

Gould, W. G. González, A. Hudak, and T Hollingsworth. 2005. Landscape fragmentation and forest fuel accumulation in Puerto Rico. EastFIRE Conference, George Mason University, Arlington VA.

Publications in press or in progress (10)

1. Davidson, A., A. Hudak, W. Gould, G. González, and T. Hollingsworth. Stand-level image segmentation with eCognition for forest landscape management. In progress.

2. González, G., W. Gould, A. Hudak, and T. Hollingsworth. Wood decay in fragmented temperate, tropical, and boreal forests. In progress.

3. Gould W., G. González, A. Hudak, and T. Hollingsworth. 2005. Downed woody debris in moist lowland and dry forest fragments in Puerto Rico. Proceedings of the Caribbean Foresters meeting. June 2004. In press.

4. Gould, A. Hudak, G. González, and T. Hollingsworth. Landscape fragmentation and forest fuel accumulation: Effects of fragment size, age, and climate. In progress.

5. Gould, W., A. Hudak, and G. González. Land use intensity and forest fragmentation: Matrix, fragment and edge. In progress.

6. Gould, W., A. Hudak, M. Quiñones, M. Jiménez, and G. González. Integrating fuel loads and edge effect in fire behavior modeling. In progress.

7. Gould, W., G. González, and A. Hudak. Landscape fragmentation and biomass accumulation in lowland moist and dry tropical forests. In progress.

8. Gould, W. M. Quiñones, M. Jiménez, G. González, and A. Hudak. Wildland fuels in Puerto Rico. IITF Remote Sensing Laboratory. In progress.

9. Hudak, A., A. Davidson, J. Evans, W. Gould, G. González, and T. Hollingsworth. Fuels mapping in mixed-conifer forests using multi resolution image and Lidar data. In progress.

10. Hudak, A., A. Robinson, W. Gould, G. González and T.A. Hollingsworth. Geographic variability in fuel accumulations in fragmented temperate, tropical, and boreal forests. In progress.

Figure 8. Wildland fuels for Puerto Rico.

Literature Cited

Harmon, M.E., and J. Sexton. 1996. Guidelines for Measurement of Woody Detritus in Forest Ecosystems. Publication No. 20. US LTER Network Office: Seattle, WA: University of Washington.

Helmer, E.H., O. Ramos, T. del M. López, M. Quiñones, and W. Dıáz. 2002. Mapping the forest type and land cover of Puerto Rico, a component of the Caribbean biodiversity hotspot. *Caribbean J. Sci.* 38, 165–183

SPSS Inc. 2002. *SPSS for windows.* SPSS version 11.5.1.