Insect population dynamics drive research publication trends:

Publication patterns related to three bark beetle species over the past 50 years.

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Abstract

Bark beetles are major agents of forest disturbance, often killing more trees than forest fires in many parts of the world. They are important drivers of forest structure and composition and play key roles in ecosystem processes. During prolonged outbreak events they can have wide ranging socio-economic costs. Because of their sometimes dramatic effect on forest ecosystems, they are a concern for land managers and the focus of much research. A systematic literature review was conducted for three species of ecologically and economically important species of bark beetles; the spruce beetle (*Dendroctonus rufipennis*), mountain pine beetle (*Dendroctonus ponderosae*), and southern pine beetle (*Dendroctonus frontalis)* from 1961-2018. Publications were grouped into nine research categories (natural history, population ecology, community ecology, chemical ecology, management, landscape ecology/remote sensing, genetics/genomics, wood science and socio-economic) that encompass common bark beetle research themes. These publications were then compared with population abundance estimates for each species to determine how research activity responds or correlates with bark beetle population dynamics. I found that, in general, publications for most research themes increase shortly after the largest outbreak events, suggesting that bark beetle population dynamics are important drivers of research output. Bark beetle management and landscape ecology were the most popular research topics, while socioeconomics, genetics, and wood science had the lowest number of publications. By systematically reviewing publications for these three species I was able to identify popular research topics and examine how they related to levels of population abundance. I hope that results from this project can be useful tools to better understand trends in research activity and the factors that drive them.

Introduction

Research Synthesis and Review Papers

Research synthesis, the integration of existing knowledge and research findings pertinent to an issue (Wyborn et al. 2017), is an important tool for efficiently digesting information from different sources, and in many forms, has become a driving force in ecology (Lortie 2014). While the necessity of synthesizing results from multiple studies to validate evidence has long been apparent, the application of research synthesis methods has only recently been more widely used and might still be generally underutilized (Chalmers et al. 2002). Meta-analysis and systematic reviews have featured prominently in the ecological sciences to handle quantities of scholarly output and data (Gurevitch et al. 2018, Arnquist et al. 1995). While meta-analysis and systematic reviews are often used to compare evidence from multiple studies, systematic literature reviews have also been used to identify and examine trends in research publications in the field of ecology (Carmel et al. 2013, McCallen et al. 2019, Uribe-Toril et al. 2019, Quiring et al. 2016). Although systematic reviews of publication trends are not common (Lortie 2014), they can provide an overview of how research is generated, consumed, and disseminated within a discipline. These reviews can highlight gaps in areas of research, summarize the expanding body of evidence, and clarify controversies (Haddaway et al. 2015). Scientometrics and bibliometrics are other related fields concerned with the quantitative features and characteristics of science and scientific research. Originally intended as an aid to more efficiently search published literature (Mingers and Leydesdorff 2015), the majority of these studies now mostly focus on measuring the output of individual researchers and institutions and examining the impact that publications generate by looking at citation metrics and other impact tools. These metrics are increasingly used by universities and government agencies to evaluate the success of research and researchers and to determine how to allocate funding and guide the direction of future research (Merigó et al. 2018). Using such metrics has been controversial, many researchers have lamented that prioritizing and incentivizing publication quantity can reduce the quality of research and might skew grant funding, university promotion, and tenure decisions (Smaldino and McElreath 2016, Sarewitz 2016). However, despite these controversies, scientometric approaches have been used to examine patterns in research topics and can be useful for studying how publications are distributed.

Within the field of entomology, meta-analysis and systematic literature reviews have become important tools integrating studies on a wide variety of topics within the field of entomology and have been used across insect categories and areas of research, from dispersal patterns in pollinators, agricultural pest control techniques, and forensic methodologies, to insect disease vectors. Typically, these approaches have focused on corroborating evidence and examining issues related to specific topics concerning one species or a group of closely related insects. Few studies have looked at broader trends in research output from within the field as a whole, or even within species and closely-related groups of insects. One example is by Chouvenc and Su (2015) who analyzed research trends across major insect categories and described how entomological research has been distributed, produced, and consumed over many years. Quiring et al. (2016) quantified publications by insect research trends in Canadian entomology and provided Other examples of bibliometric approaches include the examination of trends in global entomological research (Radhakrishnan and Priya 2018), examination of publications within a single country (Gupta 1987), within an insect order (Barros et al. 2017), within a field such as forensic entomology (Amendt et al. 2009), or more specific topics such as malaria vector resistance (Sweleih et al. 2016) or insect pest resistance to insecticides (Rothman and Lester 1985). But for the most part, few papers have quantifyied trends in entomological publications with insect population dynamics or impacts. Such a review could address general questions such as, 'which groups or insect taxa are most studied?', 'have interests and research topics changed over time, and is this consistent across taxa?', and 'do the economic impacts of an insect affect publication output?' In this paper I hope to provide an example of how a systematic literature review can be a useful tool to examine trends in research publications and determine how they relate to insect population dynamics

The growth of scientific output, measured by increases in yearly scientific publications, has been observed across broad categories of scientific research (Bornmann and Mutz 2015). Within the field of entomology, there is also a pattern of increasing publications in the last half century across most major insect categories (Chouvenc and Yao Su 2015, Radhakrishnan and Priya 2018). However, despite general increases in scientific publications, it is likely that when broken down by individual topics, species, or systems, trends in research activity will vary in response to a variety of factors, such as funding availability, socio-political factors, economic impacts of the insect, and the population dynamics of the insect, to name a few. Here, I looked at how changes in yearly research activity correlated with population abundance for three ecologically and economically important species of bark beetles in North America.

Bark Beetles

Bark beetles (Curculionidae: Scolytinae) are a diverse subfamily of weevils that spend most of their life underneath the bark of trees where they feed on tree phloem and complete their development. Bark beetles are an important forest insect that receive a lot of attention from forestland managers and researchers because of their ability to cause large tree mortality events during outbreak population phases (Lieutier et al. 2004, Vega and Hofstetter 2015). Bark beetles are some of the most destructive agents of forest disturbances in North America, often killing more trees per year than other biotic factors, and cumulatively they have affected more forested land over the last three decades than wildfires (Hicke et al. 2016, Hlasny et al. 2019). Bark beetle outbreaks have significant ecological and economic consequences (Hlasny et al. 2019); they are responsible for major economic losses for timberland owners, can negatively affect recreational activities on public lands, and affect tourism activities (Roesenberger et al. 2013). Expansions in bark beetle ranges and increases in activity and subsequent tree mortality events are frequently cited as environmental problems associated with anthropogenic climate change (Raffa et al. 2008, Brashears et al. 2005, Régnière and Fettig 2010). Although often viewed as forest pests, bark beetles are also an important part of natural ecosystems. Of the 6,000 species worldwide (Vega and Hofstetter 2015) and 550 in North America (Wood 1982), most bark beetles inhabit trees that are already dead or dying and only about one percent of species attack and kill healthy trees. These aggressive species are mostly found in the genera *Dendroctonus, Ips,* and *Scolytus* (Vega and Hofstetter 2015). Bark beetles recycle nutrients, affect the structure and composition of plant communities, contribute to canopy thinning, gap dynamics, biodiversity, soil structure, hydrology, disturbance regimes, and succession (Jenkins et al. 2008). Because of the sometimes dramatic ecological and socioeconomic impacts that bark beetles exert, a variety of silvicultural and chemical control techniques are important areas of bark beetle research (Fettig et al 2007).

Methods

Literature Search

I used the Clarivate Analytic Web of Science platform to access the Web of Science Core Collection, CABI Cab Abstracts and Global Health, BIOS citation index, and Zoological Record databases to search for literature regarding three bark beetle species (*Dendroctonus ponderosae* Hopkins, *D. frontalis* Zimmermann, and *D. rufipennis* Kirby) published between 1961 and 2018. This timeframe coincided well with published estimates of population abundance for these species. I used a basic search function to search for articles that contained the abbreviated, scientific names, and the common names in publication titles (for example: "mountain pine beetle", or "Dendroctonus ponderosae", or "D. ponderosae"). Initially this returned 2634 publications; 1,381 for the mountain pine beetle, 933 for the southern pine beetle, and 320 for the spruce beetle. So-called "grey literature" sources were included in the search; these included government documents and conference proceedings. I discarded some of the results, like non-technical pamphlets and government briefs meant for internal communication, as well as duplicate results and publications on the European spruce beetle (*Ips typographus*), which were often included in search results for spruce beetle papers. Final counts resulted in 2119 total publication, 1204 for the mountain pine beetle, 680 for the southern pine beetle, and 235 for the spruce beetle.

Research Categories

I used nine categories to describe general areas of bark beetle research (natural history, population ecology, community ecology, chemical ecology, management, landscape ecology/remote sensing, genetics/genomics, wood science and socio-economic). A brief explanation of some of the common topics within these themes and examples of papers that typify each category are listed in Table 1. Publications were classified by reading and examining each article. Since many papers could best be described as representing more than one research category, I used multiple themes for many papers.

Table 2. Common topics within each research theme category and example of papers that typify each theme.

Research Themes	Topics Included in Theme	Example Publications (MPB, SPB, Spruce beetle)
Natural history	Distribution and geographic variation Bark beetle behavior and anatomy Gallery length and density	*Reid, R.W.* 1962. *Moser, J.C.* & *T.R. Dell*. 1979. *Safranyik, L*. et al. 1995.
Population ecology	Population growth and trends Outbreak triggers and dynamics Survival, fecundity, epidemiology	*Berryman, A.A.* 1976. *Moore, G.E.* 1978. *Hansen, E.M. & Bentz, B. J.* 2003.
Community ecology	Antagonisms, mutualisms, commensalisms Predators, parasitoids, symbionts	*Six, D.L & T.D. Paine.* 1998. *Klepzig, K.D.*, et al. 2001. *Aukema, B.H*. et al. 2005.
Chemical ecology	Semiochemicals and pheromones Tree attractant and repellent compounds Tree defense and wound response	*Pitman, G.B.* et al. 1969. *Pureswaran, D.S.* et al. 2006. *Werner, R. A.* 1995.
Management	Suppression, mitigation, Silvicultural treatments, prescribed burning, Hazard risk rating schemes	*Huber, D.P.W. & Borden, J.H*. 2001. *Berisford, C.W. & Brady, U.E.* 1986. *Reynolds, K.M. & Holsten, E.H.* 1996.
Landscape ecology/ Remote sensing	Forest and stand characteristics, structure, function, dynamics, susceptibility, Digital imagery, aerial detection surveys	*Wulder, M.A*. et al. 1984. *Coulson, R.N.* et al. 1999. *Veblen, T.T.* et al. 1991.
Genetics/ genomics	Genetic diversity and population structure	*Sturgeon, K.B. & Mutton, J.B.* 1986. *Schrey, N.M.* et al. 2008. *Maroja, L.S.* et al. 2007.
Wood science	Utilizing beetle killed timber Wood quality, forest product research	*Woo, K.L*. et al. 2005. *Sinclair, S.A. & Ifju, G.* 1979. *Berlin, A.* et al. 2007.
Socio-economics	Effects on landowners/users Political, social, economical factors	*Potts, D.F.* 1984. *Buhyoff, G.J.* et al. 1979. *Flint,C. G.* 2006.

Estimates of Population Abundances

Bark beetle outbreaks can encompass hundreds to millions of acres per year, so areas of tree mortality associated with bark beetle activity can be used to estimate population abundance on a large scale (Price et al. 1992). I obtained yearly tree mortality estimates from the United States Forest Service's Forest Health and Protection's Annual Insect and Disease Conditions Report (USDA 2019) and from the Natural Resources Canada National Forestry Database, Forest Insects (NRC 2018).

Land managers and scientists have long been interested in documenting forest pest activity and bark beetle damage. Early written observations in the US and Canada date back to the 1700's (Quiring et al. 2015, Price et al. 1992), but consistently reliable surveying and comprehensive documentation didn't begin until the mid-20th century when more rigorous surveying methods were developed, standardized and documented. Comprehensive reports of abundance were not available for the spruce and mountain pine beetle until 1975. For the southern pine beetle, the most consistent and continuous data contained information about outbreak "spots" per county throughout the southern US (Pye et al. 2008). These spot counts recorded local beetle outbreaks based on spots per thousand acres of available host trees. Other estimates, such as tree mortality and timber loss were available, but were not reported for every year between 1961 and 2018. The spot data, when plotted on the same axis as the available tree mortality area data, match very closely and suggests that the two sets of data are equivalent. I used spot counts for the southern pine beetle, since they were used from 1961-2018. The spot counts from 1961-2004 are from the US Forest Service's Southern Range Experiment Station (Pye et al. 2008) and I extrapolated the Annual Insect Disease and Conditions Report to complete the time period from 2004-2018 (USDA 2019), so for this period the mortality estimates are predicted and not observed.

Comparing Trends in Research and Publications within and across Beetle Species

To observe the relationship between population abundance levels and publications, I used linear regression analyses to compare the relationship between annual bark beetle abundance and annual publications. This was repeated for each research category for each of the three beetle species. To test for the effect of time delays, tree mortality estimates at time *t* were correlated with annual publications at time *t*-1, *t*-2, *t*-3, *t*-4, and *t*-5 to account for and estimate the amount of time it should take from when an outbreak occurs to when literature might be published in response. For the publication time-series I used a 5-year moving average to smooth out yearly fluctuations. This moved the starting date to 1965 (rather than 1961).

By comparing trends across the three species, I could assess whether particular research topics were driven more by beetle population dynamics or by general bark beetle publication trends. I performed correlation tests for each research theme, correlating publications within that research category with each species of bark beetle, producing a three-way correlation table. For example, for each research category, I tested for correlations in yearly publications, such as MPBxSB, MPBxSPB, and SPBxSB. If research themes across the three beetle species were more closely related to each other than to their corresponding yearly population abundance levels, I rejected the hypothesis that bark beetle population dynamics were driving the production of literature on that particular research topic, because bark beetle populations across the three species are not correlated.

Results

Population Abundance and Total Publications

The largest recorded mountain pine beetle outbreak began in British Columbia, Canada in the late 1990s and early 2000s, with total mountain pine beetle activity peaking in Canada in 2005 (Fig 1). In the United States, the mountain pine beetle outbreak reached its highest levels of activity in the central Rocky Mountains in 2009 (USDA 2019, NRC 2018). Cumulatively, the outbreak in Canada affected almost twice as many acres as in the US. When combined, tree mortality for the two countries was highest in 2009, when roughly 30 million acres of forest experienced significant tree mortality. Although the second largest outbreak period is dwarfed by the most recent one, around 5 million acres of forest were affected in the late 1970's and 1980's across Canada and the US. While the population dynamics of both the southern pine beetle (Fig. 2) and spruce beetle (Fig. 3) exhibited more frequent fluctuations, both had a few notable peaks in population levels. The southern pine beetle's highest population abundance was in the 1970s when roughly 350 spots were recorded, resulting in tree mortality across an estimated 40 million acres (Fig. 2) in the southeastern US (Pye 2008, USDA 2019). Other notable peaks occurred in the mid-1980s and recently in the early 2000s when around 200 spots were recorded, each affecting roughly 20 million acres. Spruce beetle activity was highest in the mid-1990s, affecting over 1 million acres in Alaska, which also coincided with outbreaks in Canada's British Columbia and Yukon territories that affected almost 2 million acres (Fig. 3) (USDA 2019, NRC 2018). British Columbia has also experienced more recent outbreaks, starting in 2014, that have affected approximately one million acres.

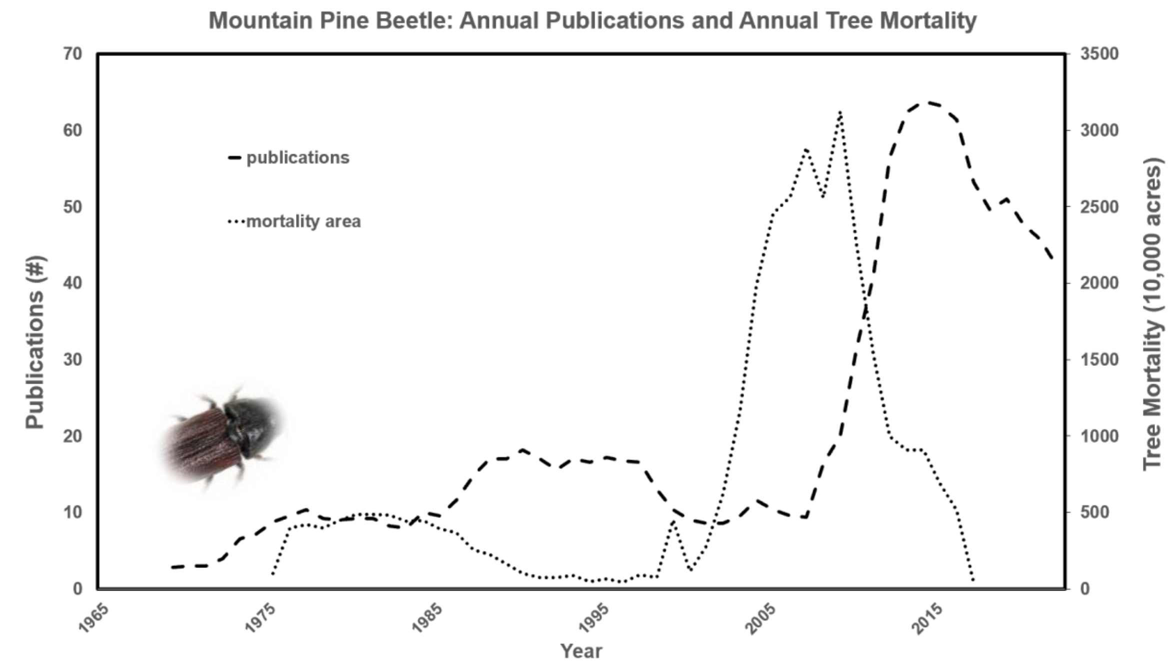

Figure 1. Annual population abundance for the mountain pine beetle (represented by tree mortality, dotted line) and total yearly publications (dashed line).

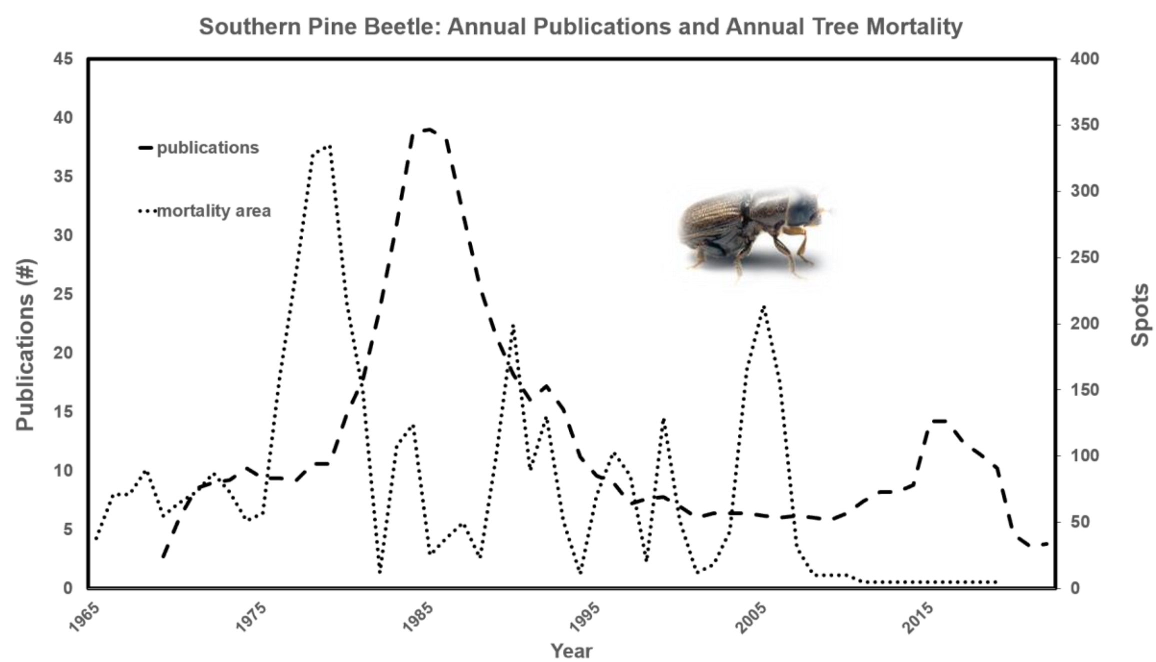

Figure 2. Annual abundance for the southern pine beetle (represented by infestation 'spots', dotted line) and total annual publications (dashed line).

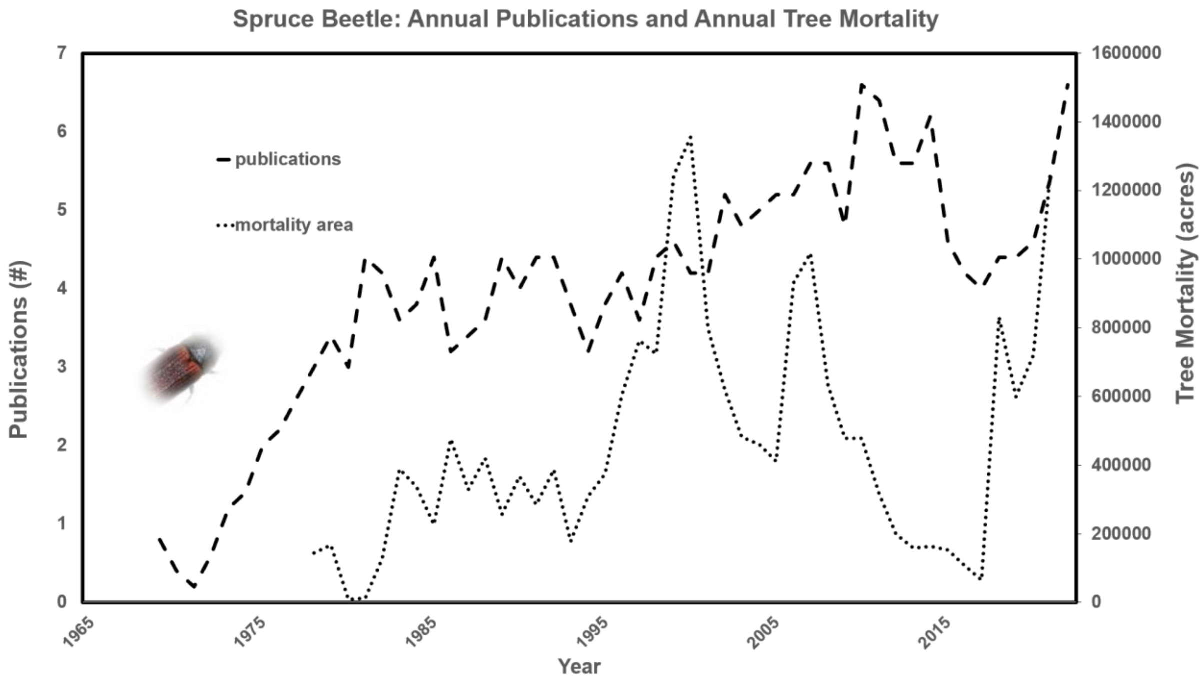

Figure 3. Annual population abundance for the spruce beetle (represented by acres of tree mortality, dotted line) and total annual publications (dashed line)

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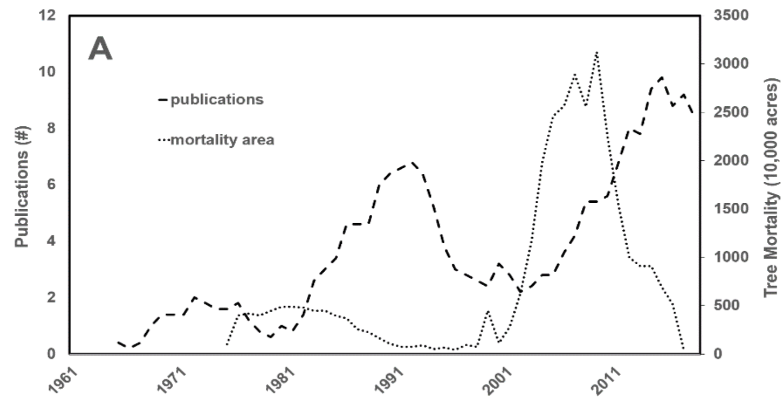
Figure 4. Mountain pine beetle: Annual publications for each research category.

A. Chemical ecology B. Community ecology C. Management D. Landscape ecology E. Natural history F. Population ecology G. Genetics H. Wood science I. Socioeconomics



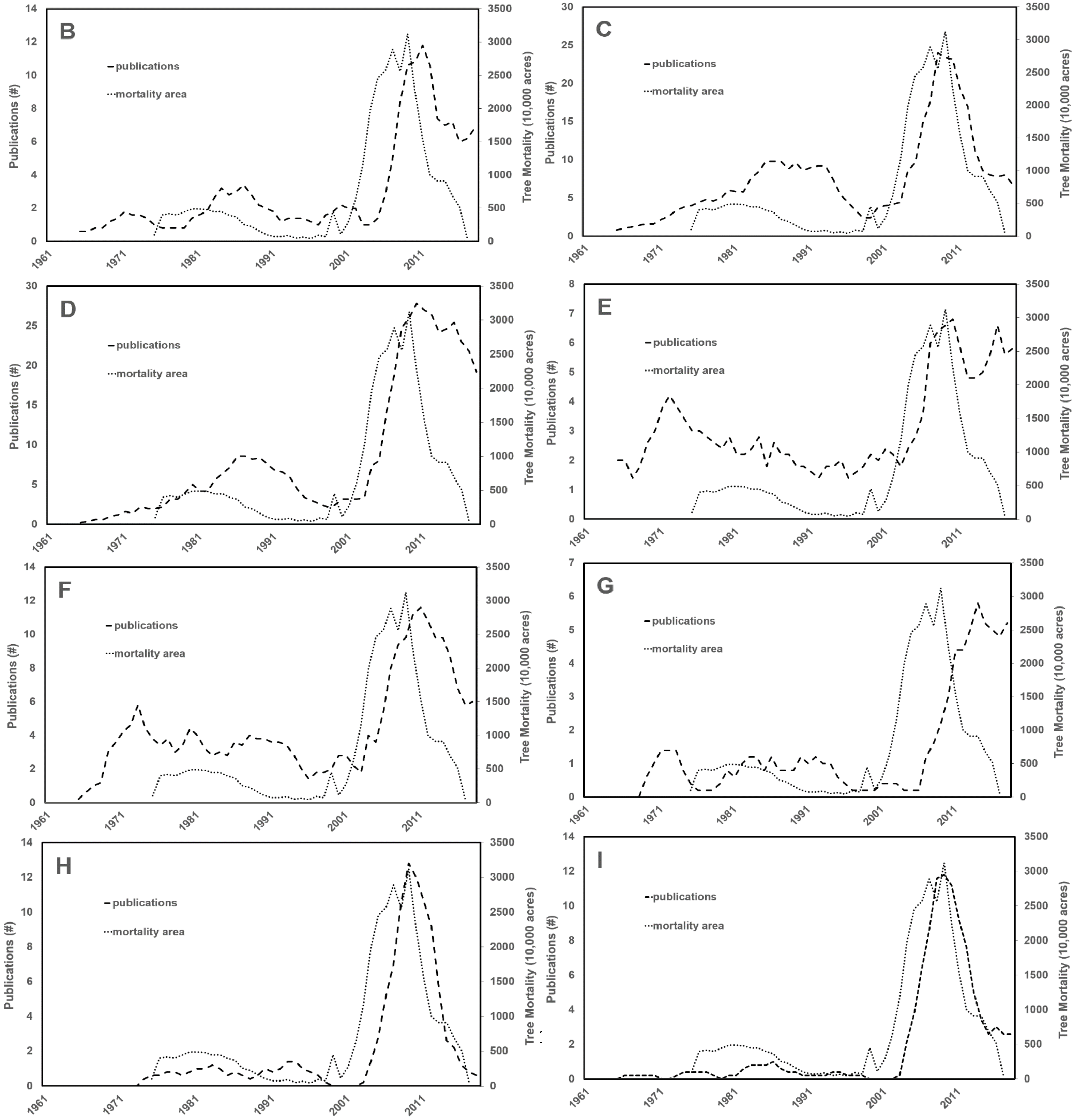
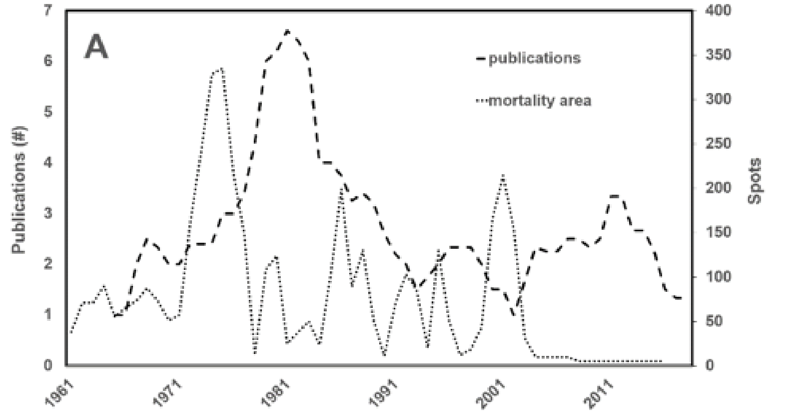


Figure 5. Southern pine beetle: Annual publications for each research category.

A. Chemical ecology B. Community ecology C. Management D. Landscape ecology E. Natural history F. Population ecology G. Genetics H. Wood science I. Socioeconomics



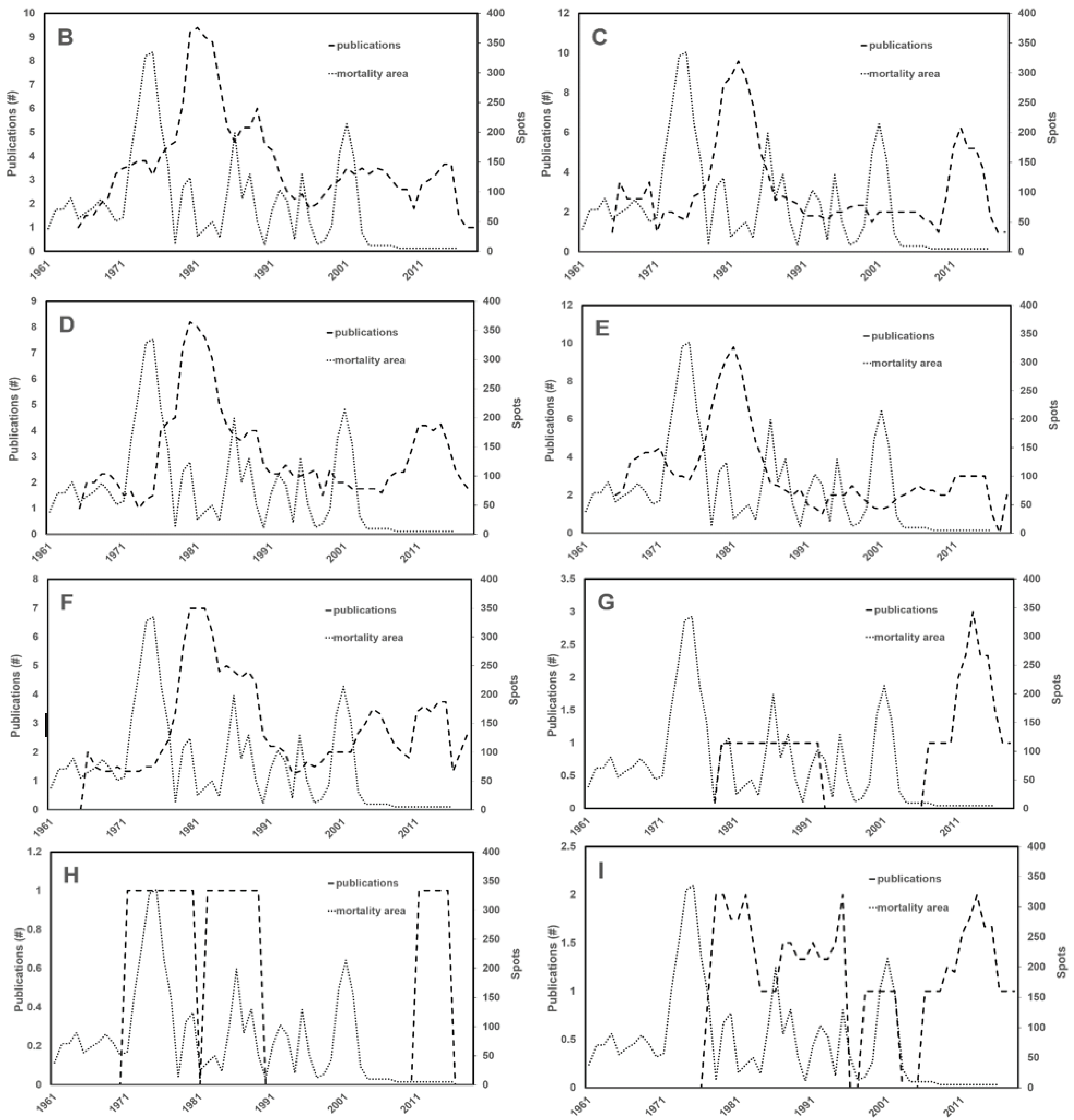
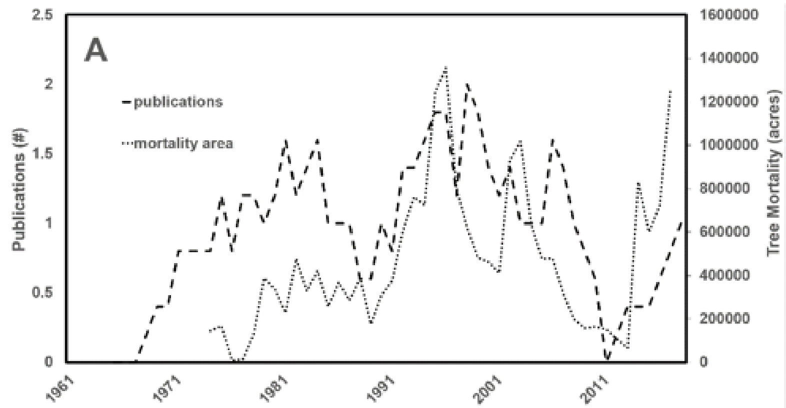
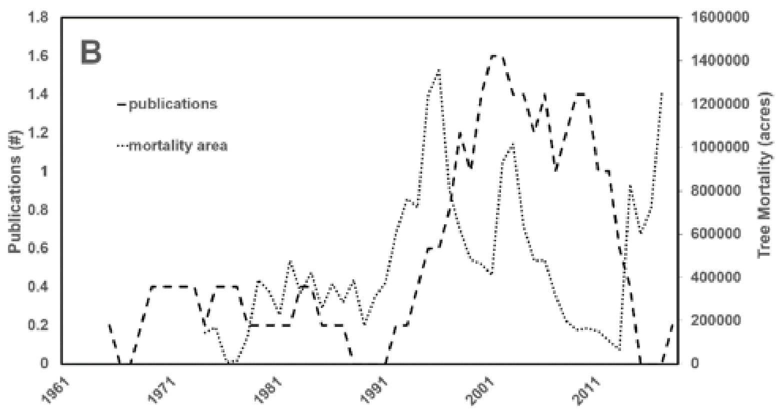
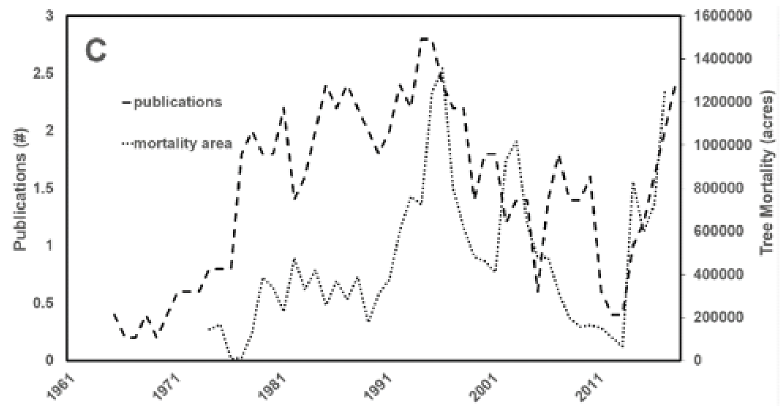


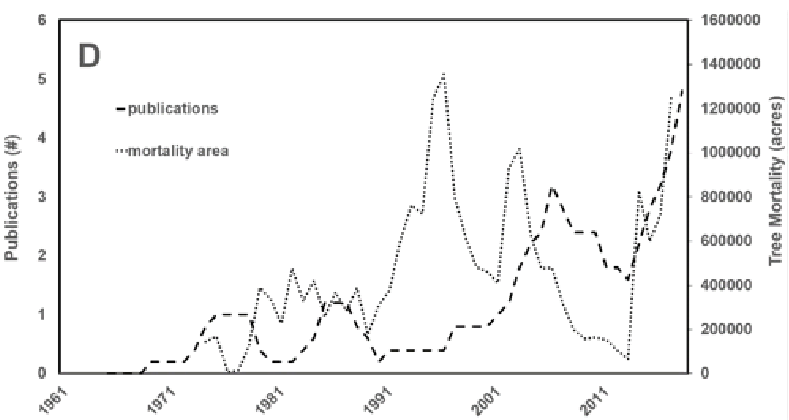
Figure 5. Spruce beetle: Annual publications for each research category.

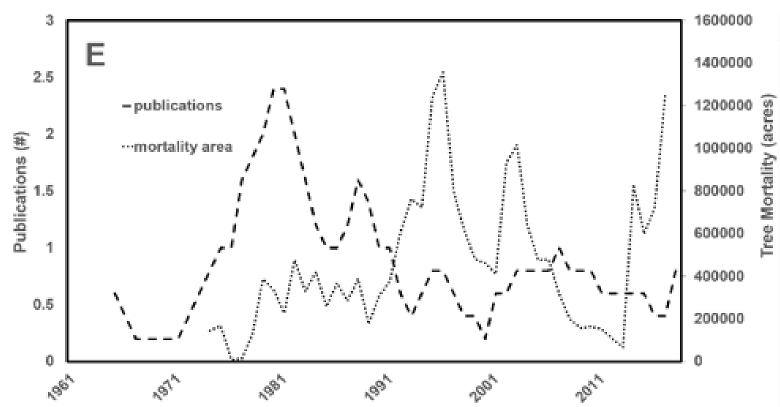
A. Chemical ecology B. Community ecology C. Management D. Landscape ecology E. Natural history F. Population ecology G. Genetics H. Wood science I. Socioeconomics

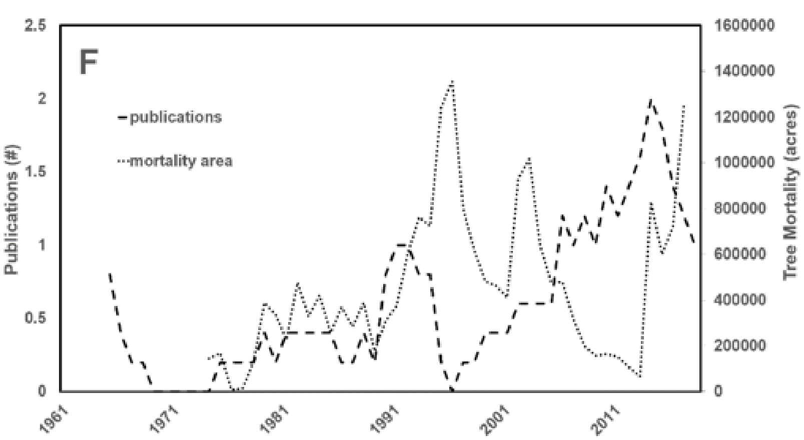












Research Themes

Total publication activity varied by research category and in some cases by bark beetle species (Figures 4-6, Table 2). In general, management and landscape ecology were the two most published themes for all bark beetle species, representing an average of 20.6% and 21.9% of publications, respectively. The themes of genetics, wood science, and socioeconomics had the lowest percentage of publications across all species, with an average of 2.2% for genetics, 1.9% for wood science, and 2.7% for socioeconomics.

For the mountain pine beetle population abundance was significantly correlated with total publications (Fig. 1) and also with publications within most research themes (Fig. 4, Table 3). Chemical ecology-themed papers had the lowest r^2 value at 0.50, while socioeconomics-themed papers appeared to be the most related, with an r^2 value of 0.94 (Table 3). The time-lag between population abundance and publication output varied by research category for the mountain pine beetle; management-themed papers showed evidence of having the shortest time lags (highest r^2 at *t*-2 years), while genetics-themed papers had the longest time between outbreaks and publications (highest r^2 at *t*- 5 years). The southern pine beetle and spruce beetle did not show strong correlations between population abundance and publication output, although r^2 values were generally higher for the southern pine beetle (Table 4). Publications for the southern pine beetle appeared to spike shortly after the first 1970s outbreak and then do not appear to have increased with subsequent outbreaks. The highest r^2 values for the southern pine beetle were 0.38 for total publications and 0.42 for the natural history research theme, both at *t*-6 years (Fig. 5, Table 4). The highest r^2 values for the spruce beetle was 0.53 for community ecology-themed papers with *t*-5 years, and total publications with an r^2 value of 0.29 at *t*- 5 years (Fig. 6, Table 5). All other r^2 values were low for the spruce beetle (Table 5). In general, publication totals per year across beetle species were very weakly correlated, the exception being a moderate correlation between the mountain and southern pine beetle for genetics-themed papers (r^2 = 0.62) (see Appendix).

Table 2. Total publications for each research theme and bark beetle species. Percent refers to the total number of papers for that species. Average percent (column on right) represents an average of the three percentages for each theme, regardless of number of publications within each beetle species.

Research Themes	Mountain Pine Beetle 1961-2018	Southern Pine Beetle 1961-2018	Spruce Beetle 1961-2018	Average Percent
Natural history	182 (8.9%)	**144 (15.8%)**	50 (14.9%)	13.2%
Population ecology	**69 (12.2%)**	135 (14.8%)	36 (10.7%)	12.5%
Community ecology	177 (8.6%)	**182 (20%)**	31 (9.2%)	12.6%
Chemical ecology	220 (10.7%)	121 (13.3%)	**55 (16.4%)**	**13.4%**
Management	**420 (20.5%)**	**146 (16%)**	**85 (25.3%)**	**20.6%**
Landscape ecology/ Remote sensing	**498 (24.4%)**	137 (15%)	**72 (21.4%)**	**21.9%**
Genetics/ genomics	85 (4.1%)	13 (1.4%)	4 (1.1%)	2.2%
Wood science	105 (5.1%)	5 (0.5%)	1 (0.3%)	1.9%
Socio-economics	108 (5.2%)	26 (2.8%)	1 (0.3%)	2.7%
Total papers	**1204**	**680**	**235**	
Total topic themes	2040	909	335	

Table 3. Relationship between publications and population abundance of the mountain pine beetle (*Dendroctonus ponderosae*) at time lags from 0 to 5 years. Values are r^2 values from linear regression analysis.

time lag (yrs)	All publications	Chemical ecology	Community ecology	Natural history	Landscape ecology	Management	Genetics	Wood science	Socio-economics	Population ecology
0	0.35	0.005	0.27	0.40	0.32	0.51	0.02	0.60	0.71	0.35
1	0.57	0.046	0.51	0.46	0.53	**0.77**	0.10	0.80	**0.89**	0.58
2	0.75	0.11	0.73	**0.70**	0.70	**0.82**	0.23	**0.90**	**0.94**	0.76
3	**0.86**	0.22	**0.87**	**0.73**	0.81	0.76	0.41	**0.87**	0.86	**0.89**
4	**0.87**	**0.34**	**0.89**	0.68	**0.84**	0.56	**0.61**	0.70	0.67	**0.91**
5	0.81	**0.50**	0.82	0.61	**0.82**	0.35	**0.80**	0.46	0.44	0.85

Table 5. Relationship between number of publications in each research theme and population abundance of the southern pine beetle (*Dendroctonus frontalis*) at time lags from 0 to 5 years. Values are r^2 values from regression analysis. Research themes with less than 5 annual publications were removed.

time lag (yrs)	all publications	chemical ecology	community ecology	genetics	landscape ecology	management	natural history	population ecology	socioeconomics
0	-0.000006	0.0032	0.0004	-0.024	-0.0168	-0.03	-0.007	-0.017	-0.03
1	0.016	0.0002	0.0078	-0.17	-0.006	-0.03	-0.007	-0.002	-0.1
2	0.061	0.01	0.0144	-0.16	0.002	-0.01	0.02	0.001	-0.04
3	0.13	0.07	0.0015	-0.13	0.03	0.0005	0.08	0.06	-0.005
4	0.25	0.15	0.11	-0.07	0.09	0.016	0.21	0.16	0.0007
5	**0.36**	0.24	0.21	-0.013	0.17	0.07	0.34	0.23	0.03
6	**0.38**	**0.36**	**0.32**	-0.005	**0.27**	0.15	**0.42**	**0.24**	0.09
7	0.31	**0.33**	**0.36**	-.0027	**0.29**	**0.23**	**0.36**	0.18	0.1

Table 4. Relationship between number of publications in each research theme and population abundance of the spruce beetle (*Dendroctonus rufipennis*) at time lags from 0 to 5 years. Values are r^2 values from regression analysis. Research themes with less than 5 annual publications were removed.

time lag (yrs)	All publications	Chemical ecology	Community ecology	Natural history	Landscape ecology	Management	Population ecology
0	0.04	0.12	0.03	-0.13	0.07	0.14	0.08
1	0.08	0.14	0.06	-0.21	0.05	0.13	0.02
2	0.12	0.23	0.12	-0.25	0.09	0.08	0.0008
3	0.21	**0.23**	0.2	-0.21	0.02	0.03	-0.002
4	0.27	0.16	**0.32**	-0.2	0.03	0.01	-0.01
5	**0.29**	0.05	**0.53**	-0.17	0.001	0.001	-0.01

Discussion

Large outbreaks increased research activity

Bark beetle research activity and related publication output is influenced, in general, by beetle population dynamics. All three species showed an increase in the number of yearly publications after the largest outbreaks, after a time-delay. For the mountain pine beetle the average lag between outbreaks and an increase in publications was 3.5 years, for the southern pine beetle this was 6 years, and 5 years for the spruce beetle (although, for both the spruce and southern pine beetle the relationships were weak.) The areas of research with the shortest time between outbreak and increases in publication output were management, wood science, and socioeconomics, however for the southern pine beetle and spruce beetle the number of annual publications for these research themes were small. However, these three topics are likely related to population dynamics and are especially concerned with investigating the impacts of outbreaks, and many of these papers were governmental documents, which may have faster turnaround time than peer-reviewed scientific journal publications. The southern pine beetle and mountain pine beetle both show distinctive peaks in publications that coincide with their largest outbreak events, the southern pine beetle in the 1970s and the mountain pine beetle in the 2000s. These publications also show a corresponding decrease shortly after this, which suggests that the publication output patterns are driven by bark beetle population trends, and not part of a general trend of increasing research activity. However, the relationship between publication output and population dynamics was less clear for the spruce beetle. Although, publications increased after the largest outbreak in the mid-1990s, this pattern was not as strong as it was for the mountain and southern pine beetles. Publication totals are much lower for the spruce beetle and its outbreaks are less distinct, as tree mortality rates are lower for this species than for the mountain or southern pine beetles. Publications for the mountain pine beetle track outbreaks in the 1980s and 2000s, while for the southern pine beetle, only the 1970s outbreak showed a corresponding peak in publications even though outbreaks in the mid 1980's and 1990s affected around 20 million acres each. The outbreaks of the southern pine beetle in the 80s and 90s were more scattered and thus may have affected scientific interest or efforts in studying the beetle (Pye 2008, USDA 2019). In general, the largest bark beetle outbreaks stimulated interest among researchers, land managers, and government agencies, which likely resulted in an increase in publication output. Interestingly, the largest publication years for the southern pine beetle (in the 1980s) correlated with the publication of the book, 'The Southern Pine Beetle' (Thatcher 1980).

Research themes

Most of the publications focused not so much on the bark beetles, but on how they impacted forests. Management- and landscape ecology-themed papers were the two most popular for two of the bark beetle species, and management was among the three top themes for all three species. Many of the management-themed publications represent government documents published in response to outbreaks that describe chemical and silvicultural treatments to mitigate or suppress bark beetle activity, as well as ways to manage forests for desired future conditions. Landscape-themed publications mostly focused on quantifying bark beetle impacts and predicting how forests would respond to outbreaks. Since most total publications were published shortly after the largest outbreaks, the fact that management- and landscape-themed papers were among the most frequent seems to suggest that these themes likely receive increased attention and funding in response to outbreaks, but wane during endemic beetle years.

For the spruce beetle and mountain pine beetle, natural history-themed publications increased in output before significant outbreaks. Publications on natural history in the mountain pine beetle also increased after the outbreak in the 2000s. Most of these papers addressed bark beetle behavior, and gallery length and density, which might reflect an interest in the general life history of the bark beetle. Research on seasonal niches and resource utilization are important areas of study during outbreaks and their popularity after large outbreaks, especially with the mountain pine beetle, might reflect a sustained interest in this topic.

Community ecology was the most popular theme for the southern pine beetle and as a percentage of total publications had twice as many publications as for the other two beetles. This could be driven by the increased knowledge and interest in fungal and mite associates and the role that competitors and predators have in influencing beetle dynamics. Its unique popularity might be due to different priorities in management and/or trends in on-going research for the southern pine beetle compared to the other two species. Since the southern pine beetle outbreaks were often shorter in duration than for the mountain pine beetle, it is possible that funding obtained during outbreaks may not be allocated quickly enough to research epidemic bark beetle populations, and research might have shifted to organisms living on bark beetles (e.g. phoretic mites, Ophiostomatales fungi, yeasts) or in infested trees (e.g. insect predators and competitors) that could be conducted with smaller beetle populations.

Genetics, wood science, and socioeconomics were the least frequent research themes for all three beetle species. Wood science and socioeconomics are the two themes that are most likely driven by beetle population abundance. The wood science-themed publications here were almost exclusively about utilizing timber killed by bark beetles, which receive little attention when beetle populations are endemic. Their increased popularity among mountain pine beetle publications might reflect the importance of utilizing the large quantity of beetle-killed trees in Canada, and the fact that Canada has more publicly-owned timber, and thus prioritizes government-backed research on this topic compared to the southern U.S. states which have mostly privately-owned timberlands. It is also possible that the wood science publications may have traditionally been published in non-peer-reviewed scientific publications, which I did not use in this study. The socioeconomics-themed papers appeared almost solely after outbreaks, suggesting an interest in the effects of tree mortality impacts on local communities and industries. Genetics was one of the least common topics among the three beetle species, but, as a percentage of total publications was a more common theme for the mountain pine beetle. This could be because the mountain pine beetle's largest outbreak was in the 2000s when genetic research became more accessible and relatively less expensive than during previous outbreaks. It is also possible that the increased attention also resulted from the fact that the mountain pine beetle had expanded geographically and into novel host trees.

How population dynamics influence research activity

Certain topics received increased focus during and shortly after beetle outbreaks. This is likely due to the increased interest in studying the effects of outbreaks on forest ecosystems. The numbers of management, landscape ecology, wood science, and socioeconomics-themed papers increased shortly after the largest outbreaks. However, those increases might not be indicative of sustained future interest, but instead may represent a short-term response to study the effects of the outbreak. Other topics, such as community ecology, chemical ecology, natural history, and population dynamics are expected to follow more general trends related to ongoing research and not be as responsive to outbreaks. Other factors, such as greater scientific interest in a topic, an increase in the number of entomological journals, and improvements in research practices and technology could generate a pattern of increasing publications over time for these topics. However, with the exception of natural history and genetics for the spruce beetle and mountain pine beetle, research trends most related to beetle population dynamics, and publications seemed to generally increase in response to outbreaks for all research categories. Increased interest and awareness during outbreaks likely resulted in more allocated funds and resources for bark beetle study, not only by entomologists but also by scientists in other fields, such as genetics and informatics. During and shortly after outbreaks, government agencies, land managers, and funding institutions are more willing to allocate resources toward bark beetle research (Abrams et al. 2018, Thatcher et al. 1980) because of the dramatic effects that the outbreaks have on forest ecosystems, nearby communities and timber industries. Consequentially, there is a relative lack of research conducted when bark beetle levels are endemic, which is likely driven by limited funds.

The status of a bark beetle's population phase, whether at endemic or epidemic levels, is important for understanding beetle ecology and for predicting future outbreaks (Vega and Hofstetter 2015). For example, Wallin and Raffa (2002) found that changes in host selection behavior were dependent on the number of beetles already occupying a host tree, and it is likely that the biology and behavior of beetles is different depending on the population phase. Therefore, results of research conducted at one population phase may not be applicable to another phase and it is important to conduct research not just during or shortly after outbreaks but during endemic population phases as well. Research activity is also affected by the duration of the outbreak, and when funding is allocated. For less severe or shorter duration outbreaks, the time to submit proposals and be awarded research funding would cause asynchrony between the proposed research and the beetle population phase. In this case, researchers with newly allocated funds would need to switch their focus to topics not directly related to active outbreaks. Larger outbreaks with longer durations allow adequate time for allocation of funds and research to be completed. In any case, most of the research was conducted on beetle outbreak populations, and funding for research to study endemic populations and incipient population decline would allow for a better understanding of population triggers and controls.

Conclusion

There are a variety of factors that influence how research is conducted. These include available funding, management concerns and objectives, advances in technology, and current trends in ongoing research. For bark beetles, at least for the three species studied here, population dynamics (extreme changes in abundance and population density) play a significant role in research activity and publication trends. Bark beetle population dynamics and their consequences for tree mortality affect how research is conducted, the attention given to specific areas of research, and when such research is published. It would be interesting to compare these results to other groups of ecologically or economically important groups of insects, such as pollinators, different forest pests, or other species that are important for conservation, to see if there might be similar patterns of increased research activity following major environmental changes.

Professional Ethics Section

My personal ethics are pretty similar to the professional code of ethics which I have adopted as a member of the Society of American Foresters. I have long felt a connection to nature and have tried to spend as much time outdoors as I possibly can. Being outside and enjoying different landscapes by hiking, backpacking, mountaineering, and rock climbing has been a way for me to find peace with myself and the world and to challenge myself. These activities have given my life meaning and purpose as much as anything else that I have done. Studying forestry has expanded my appreciation of these natural places and has also made me more aware of our reliance on forested lands, not only for goods and resources, but also for their aesthetic and spiritual significance, and the complex human dimensions, science, and policies that interact to dictate the impacts that we have on our environment. I think I have always wanted to have a life where I felt like I was contributing something to society and that I was doing something good. Being a forester seems like a great way for me to do that while also getting to spend time in the places that bring me happiness and that will allow me to work toward conserving and protecting the things that are most important to me.

As an aspiring professional forester and conservationist, I see my role as managing people's activities and how they impact forest ecosystems. Before I began studying forestry, I thought this was a lot less complicated than I do now. I have learned that stakeholders can have very different ideas about how forest management should be practiced, how forests should be utilized, and what objectives should be prioritized. So, while managing forests for optimum forest health and preserving natural ecosystems is most important to me, I understand that there are often other goals that landowners might have, or that might benefit society. Therefore, I think it is important to always be honest and transparent about what the goals of management practices are and what the possible outcomes might be.

My paper doesn't specifically recommend any actions or conclusions that might constitute an ethical dilemma, but through the process of researching and writing this paper I think I learned a little about different forest management practices related to bark beetles (and forest pests in general) and how ethics might relate to such practices. The most destructive bark beetles in the US and Canada are native, but their activity and the amount of tree mortality they cause (including expansion of geographic and tree-host ranges), have likely increased due to human activities (past forest management and anthropogenic climate change). This can make managing for natural ecosystems perhaps a little tricky because it might not be clear how much their activity is related to forest management and other human-activities and how much might be within their historical range of variation. This has been further complicated by different stakeholders and policy makers who have used the damage caused by bark beetle outbreaks to advocate for specific policies that might be based on previously-held beliefs or ideologies more than actually responding to concerns about managing for bark beetles. To deal with conflicting ideas and beliefs, I think it is important to always be specific about proposed management activities and describe the objectives, expected outcomes, and different possibilities and effects as much as possible.

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References Cited

Abrams, J., H. Huber-Stearns, M.L. Palmerin, C. Bone, M.F. Nelson, R.P. Bixler, and C. Moseley. 2018. Does policy respond to environmental change events? An analysis of mountain pine beetle outbreaks in the western United States. Environ Sci. & Policy 90: 2018:102-109.

Amendt, J., R. Zehner, D.G. Johnson, and J. Wells. 2009. Future Trends in Forensic Entomology. In: Current Concepts in Forensic Entomology (J. Amendt, M. Goff, C. Campobasso, M. Grassberger, eds). Springer.

Arnqvist, E.R, and D. Wooster. 1995. Meta-analysis-synthesizing research findings in ecology and evolution. Trends in Ecol. and Evol. 10:236-240.

Aukema, B.H., R.A. Werner, K.E. Haberkern, B.L. Clayton, and K.F. Raffa. 2005. Quantifying sources of variation in the frequency of fungi associated with spruce beetles: Implications for hypothesis testing and sampling methodology in bark beetle-symbiont relationships. Forest Ecol. Manag. 217(2-3):187-202.

Barros, T.M., L.B. Calvão, M. Vinícius, C. Vital, and L. Juen. 2017. A scientometric study of the order Odonata with special attention to Brazil. Intl. J. of Odonatology 20(1):27-42.

Bentz, B.J., J. Régnière, C.J. Fettig, et al. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. BioScience 60:602–613.

Berisford, C.W., and U.E. Brady. 1986. Field-evaluation of Fenitrothion for post-attack control of the southern pine beetle (Coleoptera, Scolytidae). J. Entomol. Sci. 21(2):139-141.

Berlin, A., C. Munoz, N. Gilkes, S.M. Alamouti, P. Chung, K.Y. Kang, V. Maximenko, J. Baeza, K. Freer, R. Mendonca, and J. Saddler. 2007. An evaluation of British Columbian beetle-killed hybrid spruce for bioethanol production. Appl. Biochem. Biotech. 137:267-280.

Berryman, A.A. 1976. Theoretical explanation of the mountain pine beetle in lodgepole pine forests. Environ. Entomol. 5:1125-1233.

Bornmann, L, and R. Mutz. 2015. Growth rates of modern science: A bibliometric analysis based on the number of publications and cited references. J. Assn. Inf. Sci. Tec. 66:2215-2222.

Breshears, D.D., N.S. Cobb, P.M. Rich, et al. 2005. Regional vegetation die-off in response to global- change-type drought. Proc. Natl. Acad. Sci. U.S.A. 102:15144–15148.

Buhyoff, G.J., W.A. Leuschner, and J.D. Wellman. 1979. Aesthetic impacts of southern pine-beetle damage. J. Environ. Manage. 8(3):261-267.

Carmel, Y., R. Kent, A. Bar-Massada, L. Blank, J. Liberzon, and Nezer. 2013. Trends in ecological research during the last three decades – A systematic review. PLoS ONE 8(4): e59813.

Chalmers, I., L.V. Hedges, and H. Cooper. 2002. A Brief History of Research Synthesis. Eval. & the Health Professions 25(1):12–37.

Chouvenc, T. and N.Y. Su. 2015. How do entomologists consume and produce their science? Amer. Entomol. 61(4):252–257.

Coulson, R.N., B.A. McFadden, P.E. Pulley, C.N. Lovelady, J.W. Fitzgerald, and S.B. Jack. 1999. Heterogeneity of forest landscapes and abundance of the southern pine beetle. Forest Ecol. Manag. 114(2-3):471-485.

Fettig, C.J., K.D. Klepzig, R.F. Billings, A.S. Munson, T.E. Nebeker, J.F. Negron, and J.T. Nowak. 2007. The effectiveness of vegetation management practices for prevention and control of bark beetle infestations in coniferous forests of the western and southern United States. J. For. Ecol Manage. 238(1-3):24-53.

Flint, C.G. 2006. Community perspectives on spruce beetle impacts on the Kenai Peninsula, Alaska. Forest Ecol. Manag. 227(3):207-218.

Gupta, D.K. 1987. Lotka's law and productivity patterns of entomological research in Nigeria for the period, 1900–1973. Scientometrics 12:33.

Gurevitch, J., J. Koricheva S. Nakagawa, and G. Stewart. 2018. Meta-analysis and the science of research synthesis. Nature 555(7695):175-82.

Haddaway, N., P. Woodcock, B. Macura, and A. Collins. 2015. Making literature reviews more reliable through application of lessons from systematic reviews. Conserv. Bio. 29:1596-1605.

Hansen, E.M., and B.J. Bentz. 2003. Comparison of reproductive capacity among univoltine, semivoltine, and re-emerged parent spruce beetles (Coleoptera: Scolytidae). Can. Entomol. 135(5):697-712.

Hicke, J.A., A.J.H. Meddens, and C.A. Kolden. 2016. Recent tree mortality in the western United States from bark beetles and forest fires. For Sci. (62)2:141-153.

Hlasny, T., P. Krokene, A. Liebhold, C. Montagne-Huck, J. Muller, H. Qin, K. Raffa, M-J. Schelhaas, R. Seidl, M. Svoboda, and H. Viiri. 2019. Living with bark beetles: impacts, outlook and management options. Science to Policy 8. European Forest Institute.

Huber, D.P.W., and J.H. Borden. 2001. Protection of lodgepole pines from mass attack by mountain pine beetle, *Dendroctonus ponderosae* with non-host angiosperm volatiles and verbenone. Entomol. Exp. Appl. 99:131-141.

Jenkins, M.J., E. Herbertson, W. Page, and C.A. Jorgensen. 2008. Bark beetles, fuels, fires and implications for forest management in the Intermountain West. For. Eco. Manage. 254(1):16-34.

Klepzig, K.D., J.C. Moser, F.J. Lombardero, R.W. Hofstetter, and M.P. Ayres. 2001. Symbiosis and competition : Complex interactions among beetles, fungi and mites. Symbiosis 30(2-3):83-96.

Lieutier, F., K.R. Day, A. Battisti, J-C. Gregoire, and H.F. Evans (eds). 2004 Bark and Wood Boring Insects in Living Trees in Europe, a Synthesis. Kluwer Academic Publishers. 569 pages.

Lortie, C.J. 2014. Formalized synthesis opportunities for ecology: systematic reviews and meta-analyses. Oikos. 123:897-902.

Maroja, L.S., S.M. Bogdanowicz, K.F. Wallin, and R.G. Harrison. 2007. Phylogeography of spruce beetles (*Dendroctonus rufipennis* Kirby) (Curculionidae: Scolytinae) in North America. Mol. Ecol. 16(12):2560-2573.

McCallen, E., J. Knott, G. Nunez-Mir, I. Jo, and F. Songlin. 2019. Trends in ecology: shifts in ecological research themes over the past four decades. Front Ecol. Environ. 17:109– 116.

Merigó, J.M., W. Pedrycz, R. Weber, and C. De la Sotta. 2018. Fifty years of Information Sciences: A bibliometric overview, Information Sciences 432:245-268.

Moore, G.E. 1978. Factors for determining population trends in southern pine beetle (Coleoptera-Scolytidae) spots. Environ. Entomol. 7(3): 335-342.

Moser, J.C., and T.R. Dell. 1979. Predictors of southern pine-beetle flight activity. Forest Sci. 25(2):217-222.

Natural Resources Canada. 2018. National Forestry Database. Forest Insects. Available at: https://cfs.nrcan.gc.ca/statsprofile/disturbance/ca. Accessed: 4/1/2019

Pitman, G.B., J.P. Vite, G.W. Kinzer and A.F. Fentiman, Jr. 1969. Specificity of population-aggregation pheromones in *Dendroctonus*. J. Insect Physiol. 15:363-366.

Potts, D.F. 1984. Hydrologic impacts of a large scale mountain pine beetle (*Dendroctonus ponderosae* Hopkins) epidemic. J. Am. Water Resour. Assoc. 20:373-377.

Pureswaran, D.S., B.T. Sullivan, and M.P. Ayres. 2006. Fitness consequences of pheromone production and host selection in a tree-killing bark beetle (Coleoptera: Curculionidae: Scolytinae). Oecologia 148(4):720-728.

Price, T.S., C. Doggett, J.M. Pye, and B. Smith (eds.). 1992. A history of southern pine beetle outbreaks in the southeastern United States. Sponsored by the Southern Forest Insect Work Conference. The Georgia Forestry Commission, Macon, GA. 65 p

Pye, J.M., T.S. Price, S.R. Clarke, and R.J.A. Huggett. 2008. History of Southern Pine Beetle Outbreaks in the Southeastern United States through 2004 (USFS Southern Research Station).

Pye, J.M., T.P. Holmes, J.P. Prestemon, and D.N. Wear. 2011. Economic impacts of the southern pine beetle. In: Southern Pine Beetle II. Gen. Tech. Rep. SRS-140 (R.N. Coulson and K.D. Klepzig, eds.). Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 213–222.

Quiring, D., V. Quiring, A. Quiring, and S. Edwards. 2016. Historical trends in Canadian forest entomology. Can. Entomol. 148(S1):S19-S32.

Raffa, KF, Aukema, BH, Bentz, BJ, Carroll, AL, Hicke, JA, Turner, MG, Romme, WH. 2008. Cross-scale drivers of natural disturbances prone to anthropogenic amplification: the dynamics of bark beetle eruptions. Bioscience. 58:501-517

Radhakrishnan, N., and S. Priya. 2018 Global research trends in entomology during 2012-2106: an analytical study. Library Philosophy and Practice (e-journal).

Reid, R.W. 1962. Biology of the mountain pine beetle, *Dendroctonus montialae* Hopkins in the East Kooting region of British Columbia. Can. Entomol. 94 605-613.

Reynolds, K.M., and E.H. Holsten. 1996. Classification of spruce beetle hazard in Lutz and Sitka spruce stands on the Kenai Peninsula, Alaska. Forest Ecol. Manag. 84(1-3):251-262.

Rosenberger, R.S., L.A. Bell, P.A. Champ, and E.M. White. 2013. Estimating the economic value of recreation losses in Rocky Mountain National Park due to a mountain pine beetle outbreak. West Econ. Forum. 12(1):31-39.

Rothman, H., and G. Lester. 1985. The use of bibliometric indicators in the study of insecticide research. Scientometrics. 8:247.

Wood. S.L. 1982. The Bark and Ambrosia Beetles of North and Central America (Coleoptera: Scolytidae), A Taxonomic Monograph. Great Basin Nat. Mem. (6) p. 1359

Safranyik, L., T.L. Shore, D.A. Linton, and S.P. Taylor. 1995. Dispersal of the spruce beetle, *Dendroctonus rufipennis* Kirby (Col, Scolytidae) from an experimental log deck. J. Appl. Entomol. 119(5):335-340.

Schrey, N.M., A.W. Schrey, E.J. Heist, and J.D. Reeve. 2008. Fine-scale genetic population structure of southern pine beetle (Coleoptera: Curculionidae) in Mississippi forests. Environ. Entomol. 37:271-276.

Sinclair, S.A., and G. Ifju. 1979. Lumber quality of beetle-killed southern pine in Virginia. Forest Prod. J. 29(4):18-22.

Six, D.L., and T.D. Paine. 1998. Effects of mycangial fungi and host tree species on progeny survival and emergence of *Dendroctonus ponderosae* (Coleoptera: Scolytidae). Environ. Entomol. 27: 1393-1401.

Sturgeon, K.B., and J.B. Mutton. 1986. Allozyme and morphological differentiation of mountain pine beetle, *Dendroctonus ponderosae* Hopkins (Coleoptera: Scolytidae) associated with host tree. Evolution 40: 290-302.

Sweileh, W.M., A.F. Sawalha, S.H. Zyoud, N.Y. Shraim, and A.S. Abu-Taha. 2016. A bibliometric analysis of literature on malaria vector resistance: (1996 – 2015). Globalization and Health 12:76.

Thatcher, R.C., J.L. Searcy, J.E. Coster, and G.D. Hertel. 1980. The Southern Pine Beetle. U.S. Department of Agriculture, Expanded Southern Pine Beetle Research and Applications Program, Forest Service, Science and Education Administration, Technical Bulletin 1631: [1980].

Uribe-Toril, J., J.L. Ruiz-Real, J. Haba-Osca, and J. De Pablo Valenciano. 2019. Forests' first decade: a bibliometric analysis overview. Forests 10(1):72.

U.S Department of Agriculture: U.S. Forest Service. 2019. Forest Insect and Disease Conditions in the United States. Available at: https://www.fs.fed.us/foresthealth/publications.shtml. Accessed: 4/1/2019.

Veblen, T.T., K.S. Hadley, M.S. Reid and A.J. Rebertus. 1991. Methods of detecting past spruce beetle outbreaks in Rocky Mountain sub-alpine forests. Can. J. Forest Res. 21(2):242-254.

Vega, F.E., and R.W. Hofstetter (eds). 2015. Bark Beetles: Biology and Ecology of Native and Invasive Species. Academic Press, Elsevier Publishing. 620 pages.

Wallin, K.F., and K.F. Raffa. 2002. Density-mediated responses of bark beetles to host allelochemicals: a link between individual behaviour and population dynamics. Ecol. Entomol. 27:484-492.

Werner, R.A. 1995. Toxicity and repellency of 4-allylanisole and monoterpenes from white spruce and tamarack to the spruce beetle and eastern larch beetle (Coleoptera, Scolytidae). Environ. Entomol. 24(2): 372-379.

Woo, K.L., P. Watson, and S.D. Mansfield. 2005. The effects of mountain pine beetle attack on lodgepole pine wood morphology and chemistry: Implications for wood and fiber quality. Wood Fiber Sci. 37:112-126.

Wulder, M.A., C.C. Dymond, J.C. White, D.G. Leckie and A.L. Carroll. 2006. Surveying mountain pine beetle damage of forests: A review of remote sensing opportunities. Forest Ecol. Manag. 221:27-41.

Wyborn, C., E. Louder, J. Harrison, J. Montambault, J. Montana, M. Ryan, A. Bednarek, C. Nesshover, A. Pullin, M. Reed, E. Dellecker, J. Kramer, J. Boyd, A. Dellecker, and J. Hutton. 2018. Understanding the impacts of research synthesis. Environ. Sci. & Poli. 86:72-84.

Appendix

Three way correlations between 3 species by research theme

Correlation between species by research theme			
total			
	mpb	*sb*	*spb*
mpb	1		
sb	**0.5233221**	1	
spb	-0.16045	-0.093742	1
chemical			
	mpb	*sb*	*spb*
mpb	1		
sb	-0.146843	1	
spb	-0.256459	0.1771326	1
community			
	mpb	*sb*	*spb*
mpb	1		
sb	0.2616643	1	
spb	-0.201515	-0.226822	1
nat hist			
	mpb	*sb*	*spb*
mpb	1		
sb	-0.152639	1	
spb	-0.152295	**0.7189598**	1
landscape			
	mpb	*sb*	*spb*
mpb	1		
sb	**0.7611731**	1	
spb	0.0735743	-0.192207	1
management			
	mpb	*sb*	*spb*
mpb	1		
sb	0.1460037	1	
spb	0.0325858	-0.007455	1
genetics			
	mpb	*sb*	*spb*
mpb	1		
sb	**0.2357521**	1	
spb	**0.7960652**	**0.3155272**	1
wood sci			
	mpb	*sb*	*spb*
mpb	1		
sb	**0.5993541**	1	
spb	-0.042177	**0.2416538**	1
socioecon			
	mpb	*sb*	*spb*
mpb	1		
sb	**0.7301524**	1	
spb	0.2164488	0.0788157	1
population			
	mpb	*sb*	*spb*
mpb	1		
sb	**0.7215229**	1	
spb	0.1073223	0.0338754	1