TRENDS IN RESEARCH PUBLICATIONS: THE RELATIONSHIP BETWEEN POPULATION DYNAMICS OF THREE NATIVE BARK BEETLES AND RESEARCH OUTPUT (1964-2009)

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ABSTRACT

Trends in research publications: The relationship between population dynamics of three native bark beetles and research output (1964-2009)

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Bark beetles are pests of North American forests due to the mortality of trees and the associated costs during their periodic outbreaks. Outbreaks often receive much attention from the scientific community and public, affecting the focus and funding of research. A common measure of research productivity is publication output and by classifying the research themes of publications it is possible to track research trends. We used three native bark beetles, the mountain pine beetle (*Dendroctonus ponderosae* Hopkins), the southern pine beetle (*D. frontalis* Zimmermann), and the spruce beetle (*D. rufipennis* Kirby), to examine the relationships between population abundance, research topics, and publication output. Due to the length of time required to allocate funding, begin research, and publish manuscript there is delay in publication output relative to beetle outbreaks. For the southern pine beetle and spruce beetle total publications tracked beetle outbreaks that were large compared to endemic populations, with a 6-10 year lag time. Although the mountain pine beetle outbreak in Canada which began in 1999 showed a five year lag, earlier outbreaks did not show a clear relationship with publication output. Natural history, population ecology, wood science and management of bark beetles are research themes that appear to be driven mostly by beetle population dynamics with an increase in publications numbers in these categories following high beetle abundance. Other topics such as community ecology, landscape/remote sensing, socio-economics, chemical ecology, and genetics might be driven by variables other than pest abundance, such as popular scientific interest or technological advancements. Currently the most popular topics of research for these three species are community ecology, management, and landscape ecology and remote sensing. Another important issue affecting research themes may be the beetle population phase when research is conducted. Due to the fluctuating population dynamics of these beetles, funding allocation may not occur until beetle outbreaks are on the decline. Natural history, population ecology, genetics, and socio-economics are all categories that would benefit from more research during endemic populations.

KEYWORDS: *publication trends, bark beetles, research themes, population phase*

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INTRODUCTION

Bark beetles (Coleoptera: Curculionidae: Scolytinae) are considered pests due to their strong negative effect on forest communities and managed land. They exhibit significant fluctuations in population density and during their periodic outbreaks are amongst the most destructive insects in North America (Payne 1980). The damage on federal and private lands caused during outbreaks can not only have significant economic effects but also have a strong influence on the scientific research of these insects. Research during endemic bark beetle levels is believed to be an extremely important but understudied area since the scientific community, forest managers and governments show increased interest and funding is more readily available following outbreaks (Thatcher et al. 1980). However, if outbreaks are short, beetle populations may have returned to endemic levels prior to funding allocation, causing researchers to struggle to locate epidemic beetle populations, mapping outbreaks, and suppression efforts. In these situations, research foci may shift to research areas that do not require the presence of large beetle populations, such as the broader beetle community or condition of wood post-outbreak.

A common measure of research productivity is publication output (Fox 1983, Howard et al. 1987, Toutkoushian et al. 2003). More publications in a given year reflect both increased research interest and productivity from preceding years. One way to determine the importance of a particular research area is to examine the peer-reviewed publication trends through time. The relative importance of a research topic at a particular time can be determined by the proportion of total publications (Faulkner et al. 2002, McCallum and McCallum 2006). Analysis of publication trends has been used in a variety of fields from psychology (e.g. Boschen 2008) to nutrition (e.g. Sabaté et al. 1999) to animal behavior (e.g. Ord et al. 2005). Comparing publication topics can help identify research patterns and these patterns can be used to make inferences about gaps in research knowledge as related to population phase of forest insects and/or the specific interests of funding agencies.

While publication output is directly influenced by the ongoing research within a discipline, areas of research are dictated by management concerns, technology, current trends and the preferences of funding agencies. However, are pest population dynamics driving certain research and publication topics? During pest outbreaks the amounts of available funding and management needs increase and consequently cause an increase in research output. This would be reflected in a rise in publication numbers, particularly in areas related to forest management, insect control and socio-economic impacts.

We examine publication trends of three bark beetles native to North America: mountain pine beetle (*Dendroctonus ponderosae* Hopkins), southern pine beetle (*D. frontalis* Zimmermann), and spruce beetle (*D. rufipennis* Kirby). All three species experience cyclical outbreaks and can cause widespread tree mortality. Their outbreaks are often integral to forest succession but have consequences for humans and forest management through reduced timber supply and revenues (Abbott et al. 2008), altered fuel loads (Billings et al. 2004, Jenkins et al. 2008), changes in fire behavior (Jenkins et al. 2008) and fire risk (Billings et al. 2004), change in forest structure and composition (Jenkins et al. 2008), increased concerns for public safety (Flint 2006), and decreased aesthetics of federal land (Flint 2006). These three species have all experienced outbreaks during the past 30 years, and due to the related human concerns, research interest is high among entomologists, ecologists, forest land owners, and managers.

We conducted a literature search of peer-reviewed research articles, classifying papers by research topics and examined research trends and their relationship with beetle population dynamics. We discuss whether publication trends are driven by pest abundance or other factors.

We also highlight current research trends, and topics which would benefit from research conducted on endemic populations. Specifically we address the following questions: 1) Do relationships exist between publication output and beetle population dynamics? 2) Which research themes are driven by pest abundance and which are not? 3) How does funding availability influence research trends? 4) Which themes are currently popular? 5) At what population phase was research on designated themes conducted? and 6) What are the future research needs for each beetle species?

METHODS

Literature search:

We used the Thomson Reuter's ISI Web of Science to search for peer-reviewed journal articles on all three beetle species (http://thomsonreuters.com/products_services/science/science_products/a-z/web_of_science). For each beetle species, we conducted an advanced search including both common and Latin name. Publication titles and abstracts were used to ensure the research was focused on the species being evaluated. We included papers on the mountain pine beetle from 1961 till 2009 since publications were not consistent prior to 1961. During this time there were 564 journal articles on the mountain pine beetle (Table 1). For the southern pine beetle, consistent publications began in 1964 and between then and 2009 we looked at a total of 458 journal articles. Publication records for the spruce beetle prior to 1975 were infrequent and are thus not included in this analysis. Between 1975 and 2009 there were 127 total spruce beetle publications (Table 1).

Research categories:

After reviewing the 1153 journal articles about all three bark beetles, we sorted them into nine categories which encompass research themes. Due to the higher volume of papers on mountain pine beetle, we assigned only one topic per publication resulting in an equivalent number of research themes classifications as articles (458). For the southern pine beetle and spruce beetle, we classified some papers into multiple categories, resulting in 658 research classifications for the southern pine beetle and 173 for the spruce beetle (Table 1).

Research themes (natural history, population ecology, community ecology, chemical ecology, management, landscape ecology/remote sensing, genetics/genomics, wood science and socio-economic) for all three beetles and number and percentage of publications are shown in Table 1. Examples of research within each theme and examples of publications are detailed in Table 2.

Insect Population Dynamics:

The Canadian National Forestry Database provided data about tree mortality by mountain pine beetle throughout Canada (http://nfdp.ccfm.org/data/comp_41e.html). For this species we only present data from Canada. Due to the disparity in outbreak sizes, the number of acres affected was log transformed for presentation purposes. Data on size of southern pine beetle outbreaks and number of spots (i.e. local infestations) in the United States for 1985-2009 were provided by the USDA Forest Service Southern Research Station (http://www.srs.fs.usda.gov/econ/data/spb/index.htm) and Forest Insect and Disease Conditions for the United States reports (http://www.fs.fed.us/foresthealth/management/fhm-conditions.shtml). Additional data on acreage in outbreak were also available from the Forest Insect and Disease Condition reports from 1972-75, 1979, and 1982. The spruce beetle data for Canada came from the Canadian National Forestry Database and data for outbreaks in Alaska from 1955-2008 were collected from Forest Health Conditions in Alaska reports and provided by

Werner et al. (2006). We converted the mountain pine beetle and Canadian spruce beetle outbreaks to acres to be consistent across all beetle species. The temporal timeframe for each species' population dynamics depended upon availability and accuracy of data. When looking at trends in number of publications over time for the spruce beetle, five-year intervals best exhibited the general trends and minimized year to year variability.

RESULTS

Mountain pine beetle:

Mountain pine beetle not only had twice as many publications as the other beetles combined, but also consistently had the greatest publication output, with 40 publications every 5 years until a jump to 206 in the late 2000s (Figure 1). Excluding some between-year variability, total publications have generally increased since the late 1980s with the greatest number of publications in 2008 (60). The top two categories, management and community ecology respectively, each contained roughly 20% of the 564 articles (Table 1). Both also displayed the same trends over the 49 year time period with two spikes in publications, one in the mid to late 1980s and the second in the late 2000s (Figure 2). Chemical ecology was the third most common topic with just over one-sixth of the articles with the majority of the papers appearing after 1980. After 1980 there were no drastic fluctuations in number of publications and an average of 2.7 publications per year. Landscape ecology/remote sensing and population ecology both averaged over 1 publication per year (1.02 and 1.4 respectively), although each theme displayed different trends. Landscape ecology/remote sensing articles do not appear till 1982 and stayed below 3 per year until 2004. However, there is a marked increase in the late 2000s with over 75% of the publications occurring after 2005. Population ecology papers first showed up in the late 1960s and remained relatively constant with few publications until the late 1990s.

From 1996-2009 articles on population ecology were found every year with an average of 2.9 publications per year.

The combined five topics mentioned above cover more than 80% of the articles. Natural history and wood science both contain between 5 and 10% of articles (51 and 30 respectively) although they display different trends through time. Natural history had its greatest number of publications in the 1960s and early 1970s while wood science had over 90% of its articles published in the 2000s. The final two topics, genetics/genomics and socio-economics, both contained 10 articles or 1.8% of the total. Genetics had the most publications in the 1980s (60%). Socio-economics first appeared in 2003 and the greatest number of publications (4) was in 2009.

In terms of population dynamics, the mountain pine beetle ranked second in the number of acres of trees killed in our dataset with 130.7 million acres killed from 1975 till 2008. There were two climaxes between 1975 and 2008, as measured by amount of forest area killed (Figure 3). The first occurred in the early 1980s peaking in 1984 with 1,193,500 acres defoliated or killed. The second outbreak began in 1999 and was much larger, peaking at over 24,838,800 acres in 2007. Currently it appears as though this outbreak is beginning to subside with 2008 having 5 million acres less killed than the preceding year.

Southern pine beetle:

An ISI search for the southern pine beetle resulted in 458 journal articles within the nine major research themes (Table 1). The highest number of publications was in 1979 (42) followed by a four year decline to just 10 articles in 1983 (Figure 4). Excluding some between-year variability, total publications have been increasing overall since the late 1980s. Over a quarter of all publications are within the community ecology category (Table 1) and excluding a spike in 1980, displays an increasing trend over the 46 year period (Figure 5). Chemical ecology contained 20.2% of the publications and remained constant over time with an average of 2.9 publications per year.

The next three most researched topics, management, natural history and population ecology, containing 50% of the articles. These three themes displayed a publication peak in the late 1970s to early 1980s although the subsequent decrease was less marked for management papers. The remaining focus areas- landscape ecology/remote sensing, socio-economics, wood science, and genetics/genomics all average less than one paper per year for the 46 year time period. Landscape ecology/remote sensing showed an increasing trend over time with the majority of the publications after 1998. The remaining three topics- genetics/genomics, socio-economics, and wood science did not have enough publications to distinguish trends.

In terms of southern pine beetle population dynamics, the amount of land infested has been steadily decreasing since the early 1970s with 1972 experiencing the most acreage killed in our dataset (60.9 million). Between 1972 and 2008, a total of 455.8 million acres were affected by this beetle. The southern pine beetle exhibited high fluctuations in the number of spots (i.e. local infestations greater than ten trees) over time with some peaks occurring across all decades. Interpreting both the number of outbreak spots and acres of susceptible forest in outbreak, there were four climaxes between 1986 and 2008 (Figure 6). These occurred around 1986, 1992, 1995 and 2000-2002 and were followed by either a single or two year decrease by at least 20,000 spots. The 1972 acreage was twice as much those recorded between 1986 and 2008. The remaining years exhibited a decreasing trend in outbreak acreage until the 1986 outbreak which was the second largest outbreak overall with 20,000 more spots and 5 million more acres than the next largest outbreak. Beetle numbers/acreage has remained low since 2003 (as of 2010).

Spruce beetle:

Spruce beetle publications displayed large inter-annual variability which complicates interpretation (Figure 7). Not until 1994 were there consistently more than 4 publications per year. Combining years into five year intervals results in a drastic increase from the 1980s to 1990s later tapering off in the 2000s (Figure 8). Community ecology was the most researched topic with over a quarter of all publications (26.6%) and shows a general increase over time with a peak of eight publications in 2006. Management was comparable with 23.7% of the publications and a peak in 2006 with six articles. Chemical ecology rounds out the top three and is similar to the first two with about one-fourth of the publications (19.1%) and a steady increase over time.

Natural history, population ecology and landscape ecology/remote sensing represent roughly a quarter of the research focus for spruce beetle articles. While natural history and population ecology remain relatively constant with slight increases in the late 1990s and early 2000s, no articles on landscape ecology were published prior to 1991 and 70% of publications in this theme were in the last decade. The final three topics (genetics/genomics, socio-economics, and wood science) had markedly fewer publications with 1.2%, 1.2% and 0.6% respectively, and no trends were discernible with so few publications.

In terms of spruce beetle population dynamics, it had the least acreage killed over time with 16.7 million outbreak acres between 1955 and 2008 (almost 8 times smaller than mountain pine beetle and over 27 times smaller than southern pine beetle). The number of acres infested with spruce beetle in Canada and Alaska varied yearly but had higher overall abundances in the 1990s and 2000s (Figure 9). Beetle populations had local outbreaks but overall infested areas remained below 375,000 acres prior to 1991. Starting in 1992, populations increased until over

1.3 million acres were infested in 1996. A second slightly smaller outbreak occurred in Canada in the early part of the 2000s with over 900,000 acres affected in 2002 and 1 million in 2003.

Publication trends across beetle species:

When looking at trends in number of publications over time, considering them in 5-year intervals reveals general trends while minimizing the impact of year-to-year variability. Comparing these intervals for the mountain pine, southern pine and spruce beetle results in two distinct trends; the mountain pine and spruce beetle have consistent increases over time while the southern pine beetle peaks early with the greatest number of publications in the late 1970s. Following this climax the number of articles dropped off but stabilized in the 1990s and began increasing again in the late 2000s.

Research themes that closely tracked beetle outbreak patterns were population ecology, wood science, natural history and management. Research themes that did not closely track beetle outbreak patterns but have generally increased over time are community ecology, landscape/remote sensing and socio-economics. Chemical ecology and genetics did not have distinctive patterns over time and did not appear to be related to insect dynamics.

DISCUSSION

Do relationships exist between publication output and population dynamics beetles?

Spikes in publications and the years in which they occur could be attributed to population outbreaks in the preceding years. Following the onset of an outbreak, we predict a time lag till publication to allow for funding allocation, research to be conducted and analyzed, and journal acceptance and publication. The first mountain pine beetle outbreak in the early 1980s shows a weak relationship with number of publications in that a definitive delayed peak cannot be discerned. Since this first mountain pine beetle outbreak is small in comparison to the later outbreaks, it may not have affected a large enough area or occurred in forests valuable enough to have captured much scientific attention. The more recent mountain pine beetle outbreak presents a clearer picture of increased publications following outbreaks. A mountain pine beetle outbreak began in 1999 and a subsequent publication spike appeared in 2004. There does appear to be a relationship between the start of an outbreak and number of journal articles with an approximate five year lag between. The drop in articles from 60 to 48 in 2008-2009, while not reflected in the preceding years' abundance, is not indicative that a downward trend in number of publications will continue. We predict the number of articles will remain high over the next few years in reflection of the outbreak growth and considerable impact on forest stands in Canada during the late 2000s.

For the southern pine beetle, we expect the publication trends to more closely follow the total acreage in outbreak rather than the number of spots since total acreage would lead to the highest economic losses. In our dataset the largest acreage killed in one year occurred in 1972 and corresponds to the most articles on southern pine beetle publications in a year (1979). The three remaining peaks (1986, 1995 and 2000-2003) are more clearly reflected by the number of spots than by total acreage and also exhibit a less clearly defined relationship of outbreaks to publications. Each peak was smaller than the preceding and had fewer publications than the 1979 spike. The corresponding publication peaks were roughly 6, 10 and 8 years after peak outbreaks, allowing adequate time for research to be conducted and published.

For the spruce beetle outbreak which began in 1991, the abundance peak in 1996 is most likely reflected in the publication spike of 2006. Since a ten year time lapse is an appropriate time frame between outbreak and publication count, the quasi-peak in abundance in 1993 is the most likely cause for the publication spike in 2003. This would also mean that we would expect to see a publication climax in 2013 as a reflection of the second outbreak in 2003. The longer time lag for spruce beetle compared to mountain pine beetle and southern pine beetle may be attributed to the much smaller scale of spruce beetle outbreaks compared to the other two, both in total acreage killed over time and the single year with greatest acreage. The greatest acreage affected by spruce beetle in a single year was 1.35 million acres in 1996, 18 times smaller than the mountain pine beetle peak of 24.9 million acres in 2007 and 45 times smaller than the southern pine beetle's 1972 acreage (60.9 million).

Which themes are driven by pest abundance and which are not?

For pest abundance to be the major driver behind a research theme, we would expect the publication trend within that theme to track beetle species' abundance over time. Due to the drastically different patterns in these beetles' population dynamics, abundance driven themes would have dissimilar trends across species but track each species population dynamics. Population ecology, wood science and management are three such categories: mountain pine beetle showed increases for all three themes, southern pine beetle showed decreases, and spruce beetle increased for wood science but had fluctuations for population ecology and management. Natural history also had dissimilar patterns implicating the importance of beetle abundance in research in this topic. Research in the first three fields are logical categories to be influenced by beetle abundance in that the dynamics of species populations, utilization and quality of beetle-killed lumber, and management-related efforts to understand and control pests would all become more relevant during and immediately following outbreaks. Although much of the research encompassed within natural history would not be expected to be affected by population abundance (i.e. gallery length and density), this category also contains papers addressing behavior, seasonal niches, and resource utilization which would be of great interest during an outbreak.

On the other hand, topics which show consistent trends across beetles over time are motivated by factors other than pest abundance. Other factors which could be driving publication trends include greater scientific interest in a topic, increased funding for research, more entomological journals available for publishing, and/or better and more available technology. Community ecology, landscape/remote sensing and socio-economics each display a clear and consistent pattern of more publications over time. Community ecology may be driven by the increase in fungal and mite associates of bark beetles as well as the role of competitors and predators in influencing beetle dynamics. Landscape/remote sensing may be driven by the increase in precision and availability of technology necessary for research in these fields. Socio-economics articles could be increasing due to newly recognized interest in public opinion, growing interest in landowner awareness and public perception, and increased accountability for expenditures on pre-outbreak mitigation actions and to quantify the aesthetic and economic costs of both mitigating actions and outbreaks.

Chemical ecology and genetics are themes where interpretation is more difficult due to different trends across beetles over time. Chemical ecology shows mountain pine beetle increases over time, southern pine beetle increases to a plateau and spruce beetle peaks in the late 1990s and early 2000s and then decreases again. This may indicate that some research within chemical ecology addressed questions of more interest to researchers during outbreaks (i.e. anti-aggregation pheromones, tree repellent compounds) while others did not. We would expect the genetics category to increase consistently for all beetles due to technological improvement and increased affordability and access to genetic tools over time. While the mountain pine beetle and southern pine beetle patterns match (increases until the 1980s and then a plateau), using the five year intervals for the spruce beetle shows a bell curve with a crest in the late 1990s and early 2000s and then a marked decrease. However, if the decadal interval is used (data not presented) the pattern matches that of the other two beetles, indicating that longer timelines may be necessary to reduce yearly variation.

How does funding availability influence research trends?

Although accurate funding information was not accessible for inclusion in this paper, we think it is an important variable in interpreting publication trends over time. Funding is influenced by outbreaks and management needs and it, in turn, influences management and research output (Figure 10). Outbreaks are times of great economic losses due to expenditures on suppression efforts (Craighead et al. 1931) and lost timber revenue (Eidmann 1992, Raffa et al. 2008). Additionally the standing dead timber causes changes in fuels structure and fire behavior and can increases the risk of catastrophic fire in some forest types (Jenkins et al. 2008). The sources of research funding dictate the future focus of research by funding proposals which address their specific concerns. The United States Department of Agriculture (USDA) has several sources of research funding, such as internal grants or cooperative agreements with universities. In Canada, the federal National Sciences and Engineering Research Council (NSERC) program funds grants for university research in science and technology. By having a competitive application process, these agencies can selectively choose proposals addressing either their concerns or, in the case of the USDA, the management needs of agencies within their department. NSERC grants to universities from 1990-2009 (data not presented) did show an increase in funding for mountain pine beetle research beginning in 2004 and increasing drastically over the next 4 years, suggesting that funding allocation for this beetle is following its outbreak dynamics.

Which themes are currently popular?

Community ecology is the most popular area of research across all three beetles and interest in this topic is unrelated to beetle population status. One plausible explanation for the continued increased interest is that funding obtained during an outbreak may not be allocated quickly enough to research epidemic beetle populations. However research on the organisms living on bark beetles (e.g. phoretic mites, Ophiostomatales fungi, yeasts) or in infested trees (e.g. insect predators and competitors) could be conducted with much smaller beetle populations. Research in management topics is the second most published theme overall (second for mountain pine beetle and spruce beetle and the third for southern pine beetle). Since these native beetles have cyclical population explosions, there is always interest in developing practices to mitigate outbreaks. The third most popular topic of research in the 2000s was landscape ecology and remote sensing. As the available tools improve to map forest compositions, stand densities and dynamics, and beetle infestations, researchers and managers will be able to get a better understanding of stand susceptibility, infestation enlargement, and beetle aggregation patterns.

At which population phases was research conducted?

We believe that the status of a beetle's population may be extremely important in interpretation of research findings. Wallin and Raffa (2002) found that changes in host selection behavior were dependent upon the number of beetles already occupying a host tree. It appears that the biology and behavior of beetles in the endemic phase in many aspects is different from beetles during the epidemic phases. Therefore, results of research done at one population phase may not be applicable to another phase.

The length of an outbreak may be the best predictor of the population phase of a beetle species when research is occurring. If an outbreak is short-lived and/or of small size (i.e. mountain pine beetle outbreak in 1980s), the necessary time to apply for and be awarded research money may be greater than the duration of the outbreak. In these instances, researchers with newly allocated funds may have to switch their focus to topics not directly related to active outbreaks. Longer term outbreaks (over five years) should allow adequate time for allocation of research funds and for a couple of years of research on growing epidemic populations. However if the population is already beginning to decline when research is started, changes in beetle behavior or community dynamics may occur, altering the goal or findings of the study. It is possible that the vast majority of research already conducted has been on outbreak populations and their decline. However, more continuous sources of funding need to be available for research on endemic populations and incipient populations to attempt to understand outbreak triggers.

What are future research needs?

Both the mountain pine beetle and southern pine beetle were at endemic population phases during the 1990s and experienced reduced publications in most research categories during that decade. The mountain pine beetle had a constant number of publications on natural history, population ecology and chemical ecology publications from the decade before; while for the southern pine beetle only chemical ecology and socio-economics remained steady. This suggests that for each beetle species there are some topics which have been explored during endemic population levels. Genetics, wood science and socio-economics had the least publications (less than ten) for both beetles during the 1990s. The mountain pine beetle was the subject of few natural history publications while the southern pine beetle also was the subject of a low number of population ecology articles during the 1990s. Of these five topics, all except wood science would benefit from more research conducted during endemic population levels. Wood science is comprised of papers researching the effects of beetle attack on lumber quality and utilization of beetle-killed trees and is not likely to have results that differ due to population phase.

Natural history and population ecology studies provide valuable information about the beetles' basic biology and population dynamics, which are necessary to develop adequate models and management strategies for pest control (Stenseth and Hansson 1981), conduct biodiversity studies, and guide potential conservation efforts (Dayton 2003, McCallum and McCallum 2006). By analyzing genetic diversity, inferences can be made about beetle dispersal distances and patterns to aid in management plans (Allender et al. 2008). Not only is public perception and understanding of the problems that bark beetles pose important, but quantifying the value they place on the surrounding forests can provide valuable input to managers formulating a management plan. Additional research in socio-economics could also address the economic costs of prevention versus suppression actions.

Due to the much reduced number of spruce beetle publications compared to the other two beetles, increased research across all themes would be beneficial. Even the most researched themes (community ecology and management) have less than 50 publications over the 35 year time set.

CONCLUSIONS

Evidence that pest abundance is the driving force behind research output does exist for the mountain pine beetle, southern pine beetle and spruce beetle and these data can be used to make inferences about future research needs. Although analysis of publication trends has been used in a variety of fields, it is not yet prevalent many areas of ecology or forestry. Publication trends would be a useful tool in building upon the available body of research by aiming future research towards understudied areas such as endemic population genetics.

Funding is an integral part of the equation as to how management needs are met and affected by research productivity. We contest that this relationship between research, management and funding would extend beyond insects that outbreak. Examining these relationships would also work with other organisms and could be applicable to other important pest species and diseases such as studying flu epidemics or deer population control.

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Table 1. Number of publications within each research theme, the percentage (in parentheses) each theme represents of the total, and the total number of papers and research themes for each of the three beetles of interest.

Research Themes	Mountain pine beetle 1961-2009	Southern pine beetle 1964-2009	Spruce beetle 1975-2009
Natural history	51 (9.0)	90 (13.7)	18 (10.4)
Population ecology	69 (12.2)	79 (12.0)	17 (9.8)
Community ecology	111 (19.7)	175 (26.6)	46 (26.6)
Chemical ecology	91 (16.1)	133 (20.2)	33 (19.1)
Management	121 (21.5)	123 (18.6)	41 (23.7)
Landscape ecology/ Remote sensing	71 (12.6)	32 (4.8)	13 (7.5)
Genetics/ genomics	10 (1.8)	7 (1.1)	2 (1.2)
Wood science	30 (5.3)	8 (1.2)	1 (0.6)
Socio-economics	10 (1.8)	11 (1.7)	2 (1.2)
Total papers	**564**	**458**	**127**
Total papers (with some papers in multiple themes)	564	658	173

Table 2. Publication topics covered within each of the nine research themes and example publications. These categories are constant across southern pine beetle, mountain pine beetle and spruce beetle.

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	Interspecific attraction Antagonisms, mutualisms and 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	Semio-chemicals 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 efforts—cut and leave, prescribed burning, insecticides Hazard rating schemes Beetle marking and trapping Protecting individual trees	*Buber, 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	Digital imagery, LANDIS, LANDSAT Stand density, structure, function, dynamics, and susceptibility	*Wulder, M.A.* et al. 1984. *Coulson, R.N.* et al. 1999. *Veblen, T.T.* et al. 1991.
Genetics/ genomics	Microsatellite loci 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 Lumber quality	*Woo, K.L.* et al. 2005. *Sinclair, S.A. & Ifju, G.* 1979. *Berlin, A.* et al. 2007.
Socio-economics	Landowner awareness Ecological and economic consequences Aesthetics, expenditure and profit	*Potts, D.F.* 1984. *Buhyoff, G.J.* et al. 1979. *Flint,C. G.* 2006.

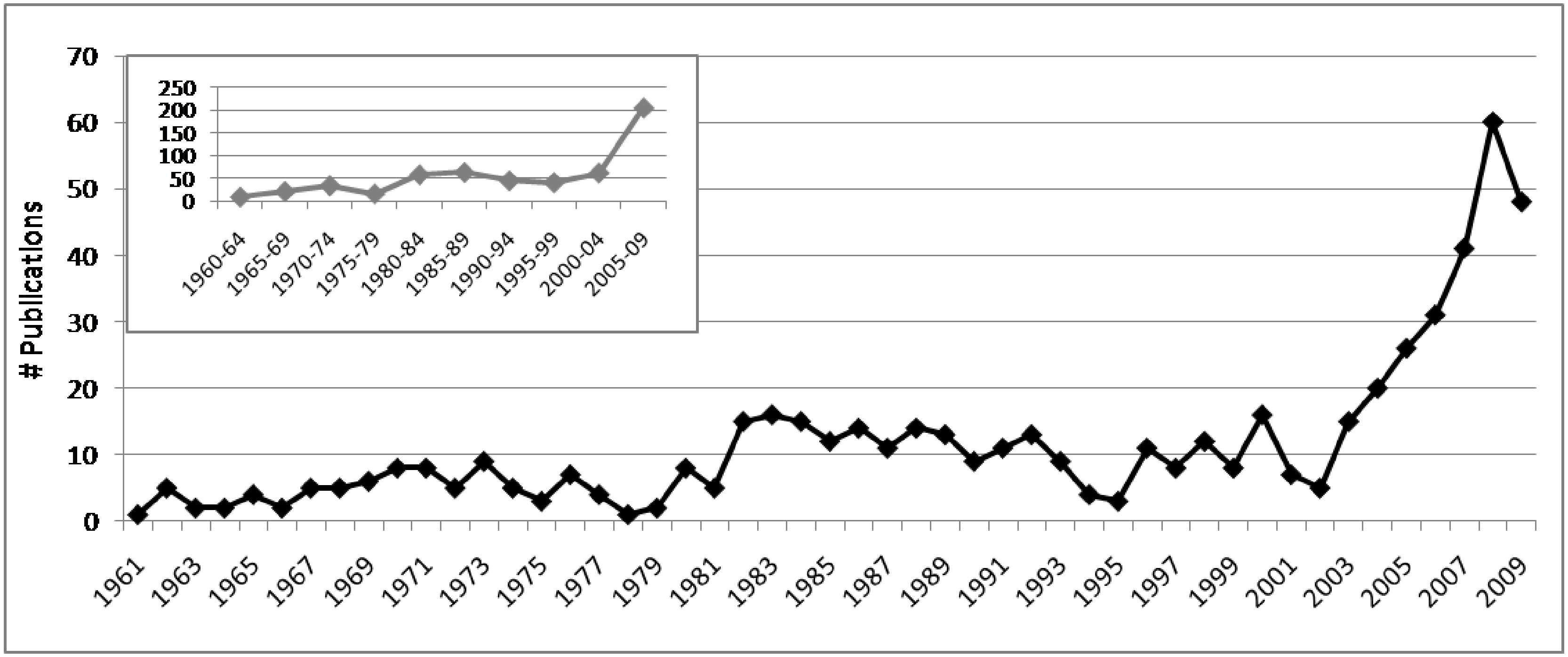

Figure 1. Total number of journal articles on mountain pine beetle from 1961 to 2009. Inset graph shows publications using five year intervals to reduce year-to-year variability. Both graphs display a drastic increase in the number of publications during the 2000s.

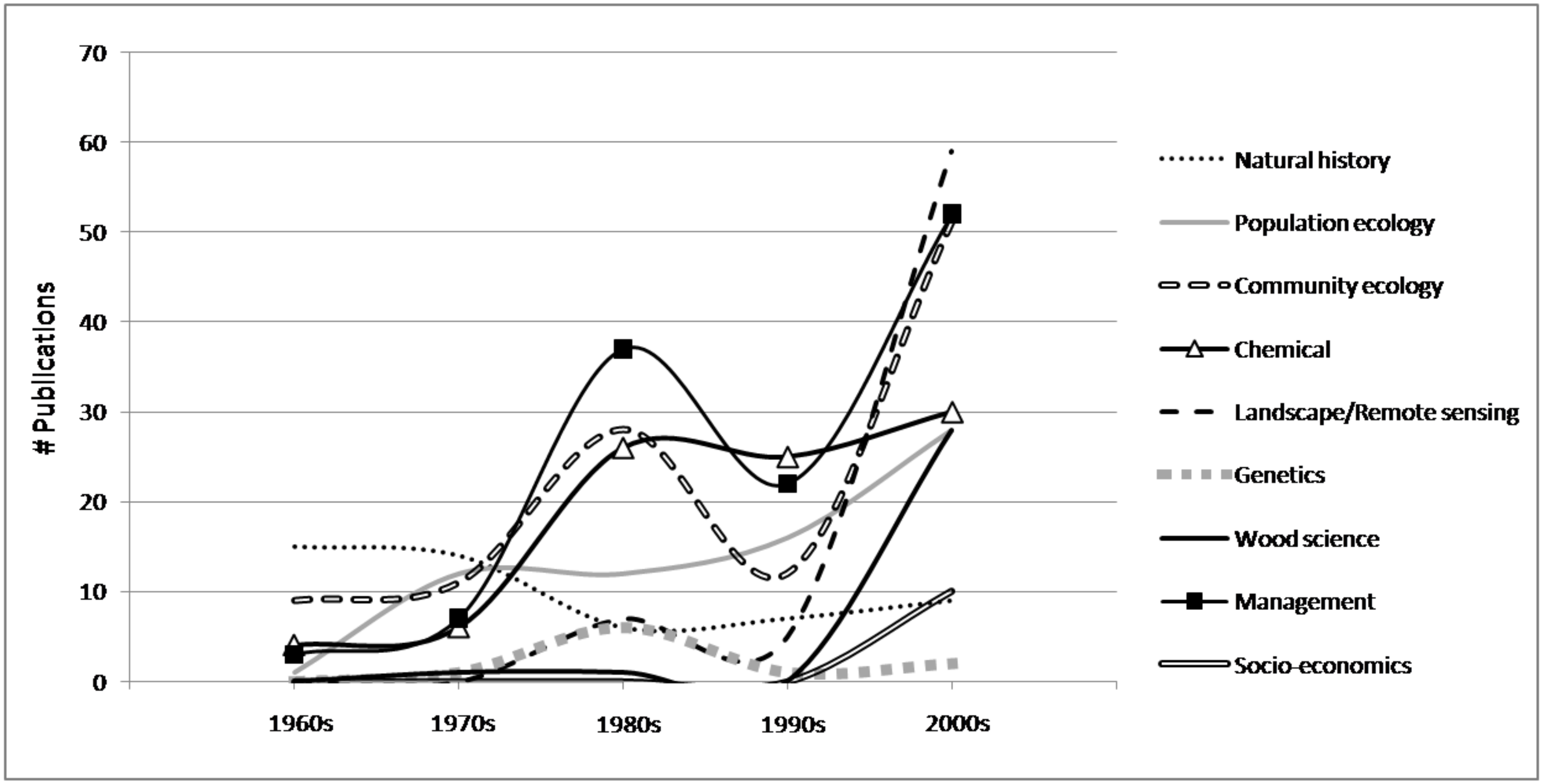

Figure 2. Decadal patterns of mountain pine beetle publications by research theme. Articles were classified into one of nine research categories based on the main focus of the study.

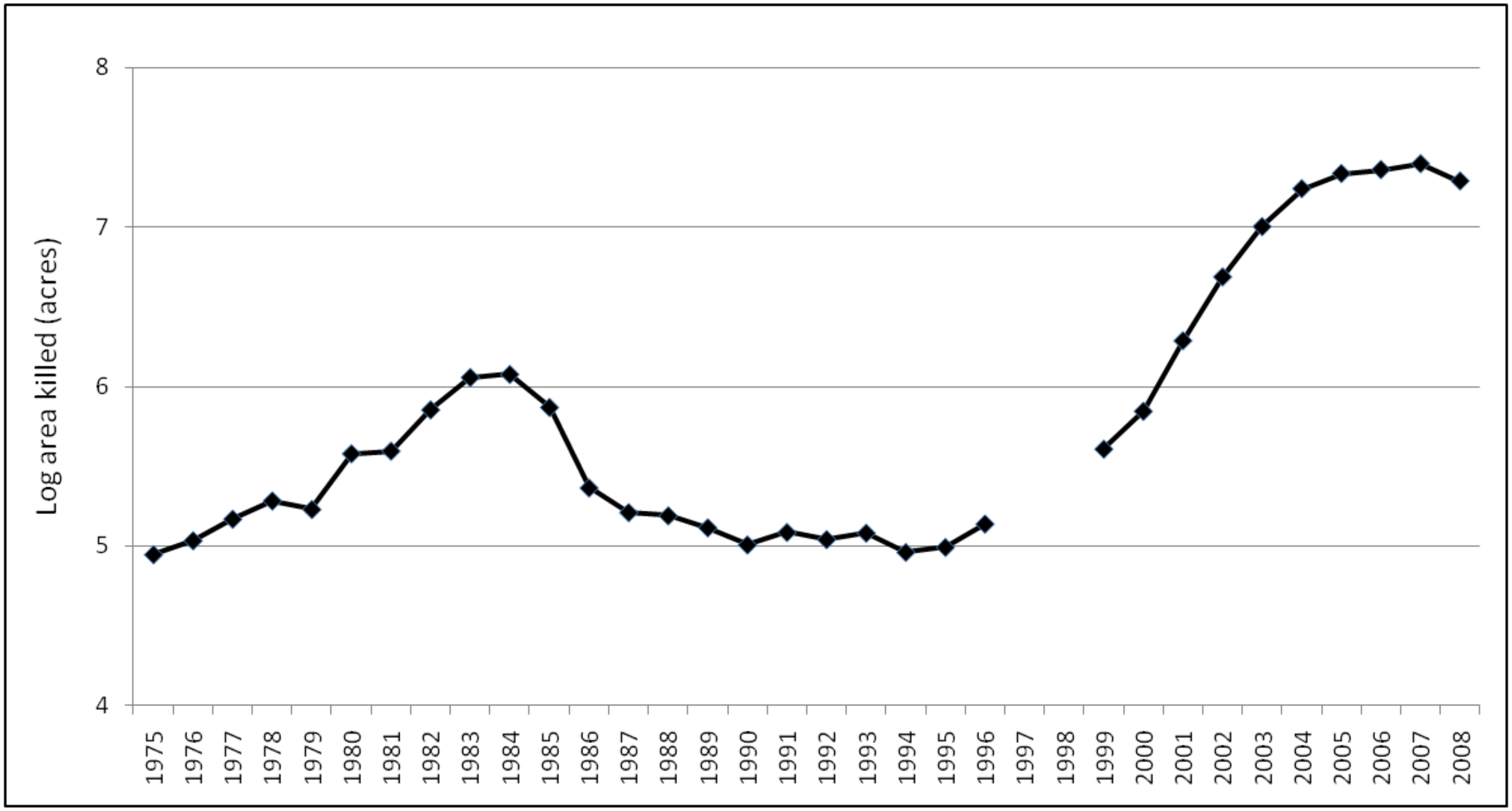

Figure 3. Relative abundance of mountain pine beetle in Canada from 1975 to 2008. Two outbreaks occurred during this time period, one in the mid-1980s and one since 1999. Due to the disparity in outbreak sizes, data were log-transformed.

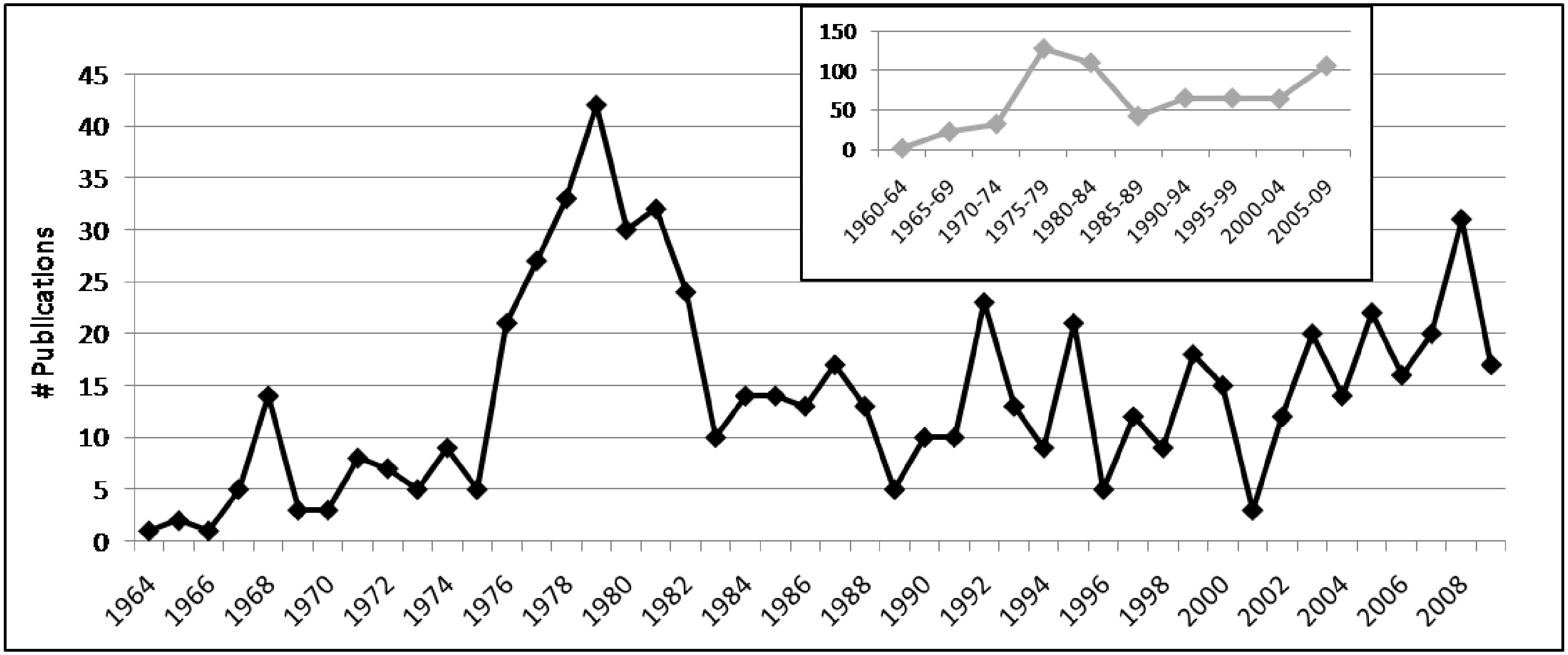

Figure 4. The total number of peer-reviewed articles on southern pine beetle from 1964 to 2009. Inset graph presents the same data using five year intervals to reduce annual variability.

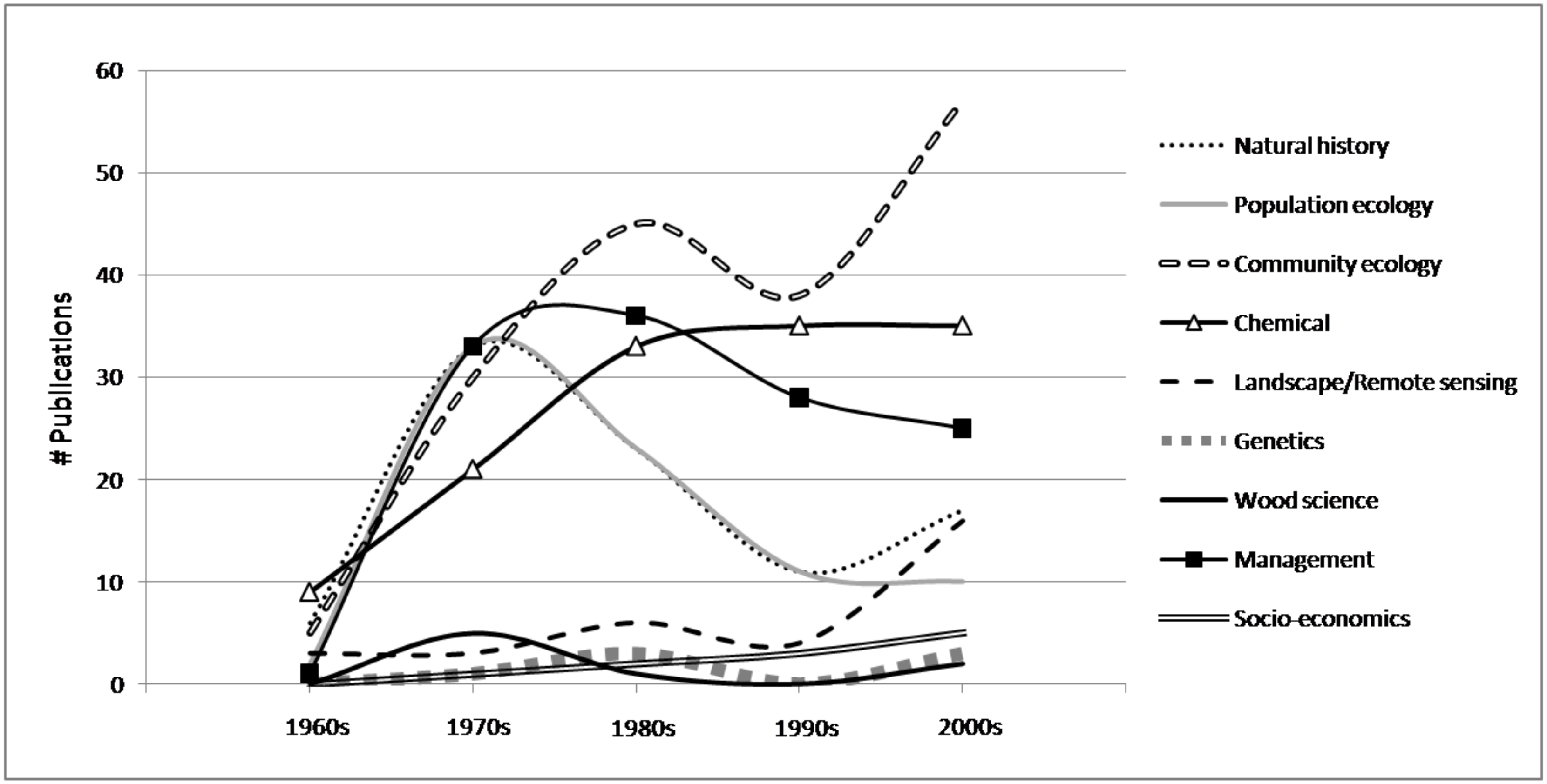

Figure 5. Decadal patterns for number of southern pine beetle publications per research theme. Articles were into multiple of the nine research categories based on the themes of the study.

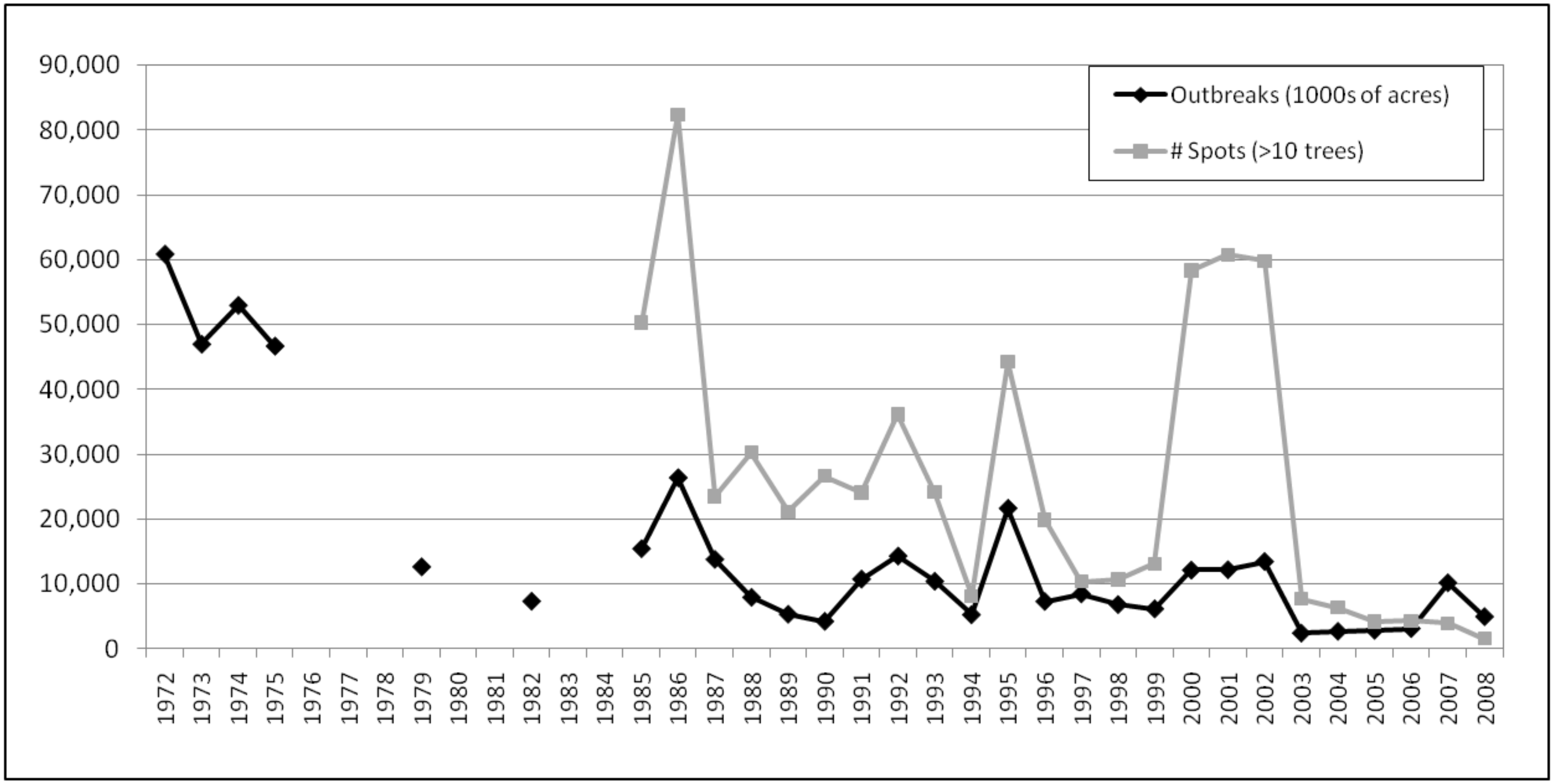

Figure 6. Abundance of southern pine beetle in the United States from 1972 to 2009 as measured by number of spots greater than ten trees (local infestations) and 1000s of acres in outbreak. Data are inconsistent prior to 1985 and only some years are presented.

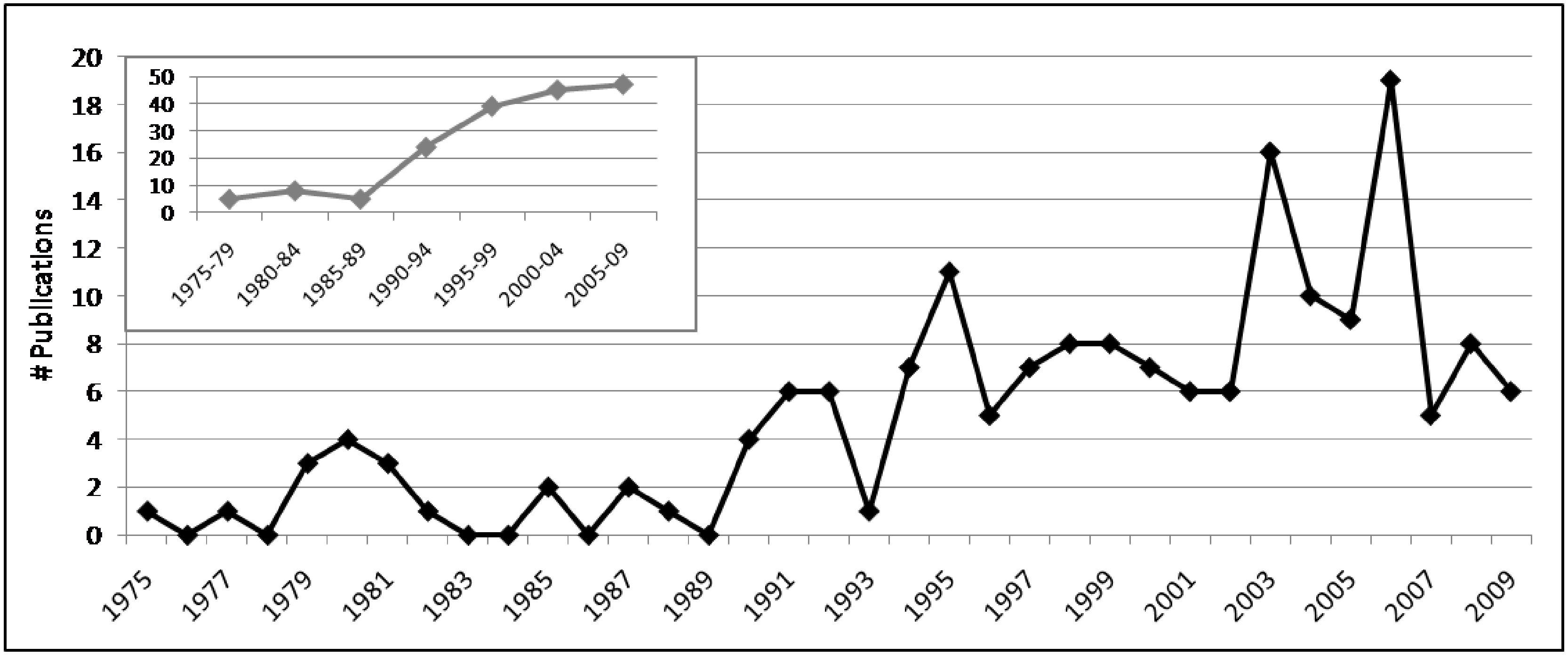

Figure 7. Total number of peer-reviewed articles on spruce beetle from 1975 to 2009. Inset graph of five year intervals shows a steady increase in publications beginning in the late 1980s.

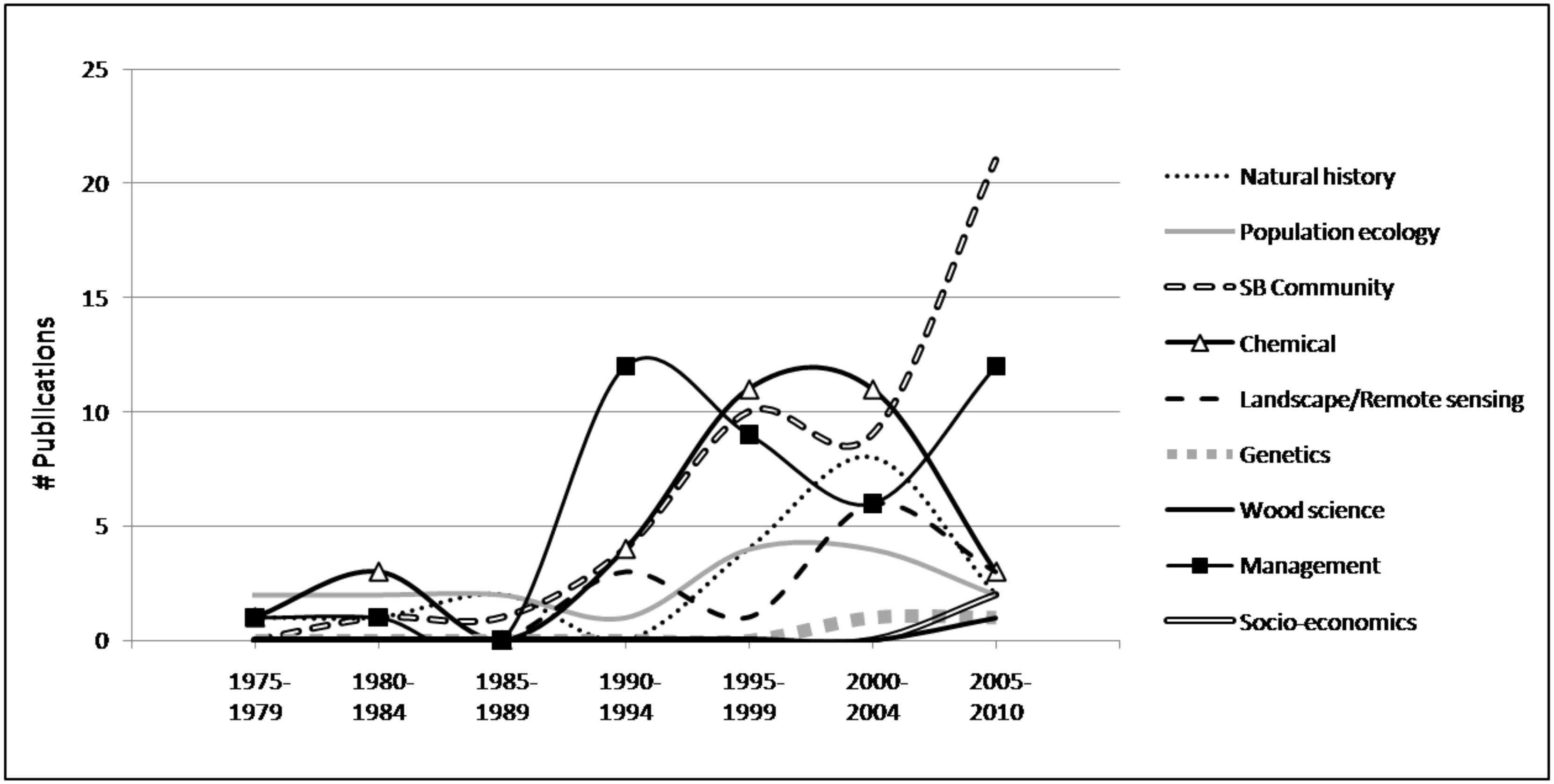

Figure 8. Spruce beetle publication trends by research theme over 5 year intervals. Articles could be classified into multiple of the nine research categories based on the themes of the study.

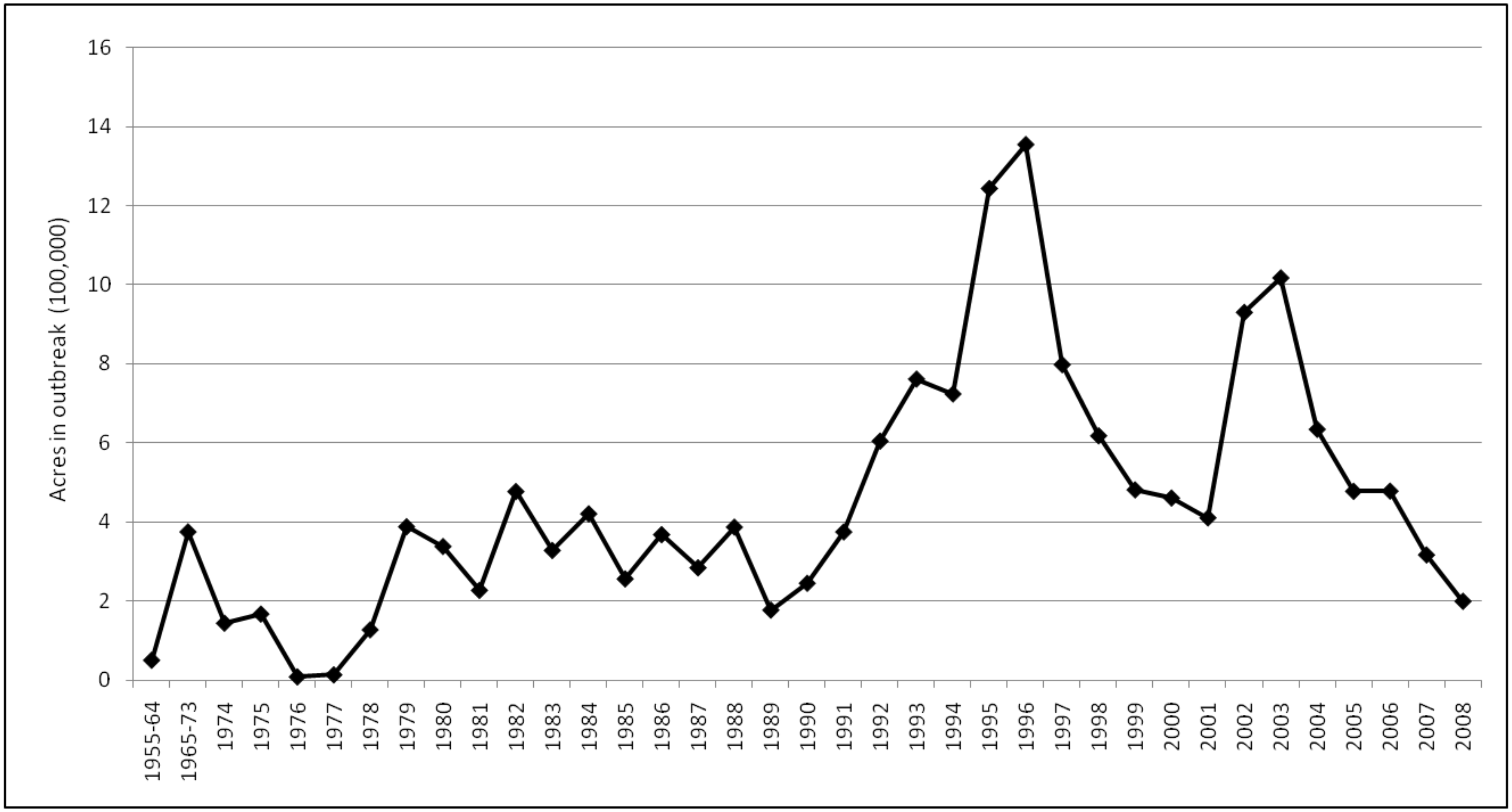

Figure 9. Acres defoliated or killed by spruce beetle in Alaska and Canada from 1955 to 2008. Individual year totals were not available prior to 1974 so grouped data are presented.

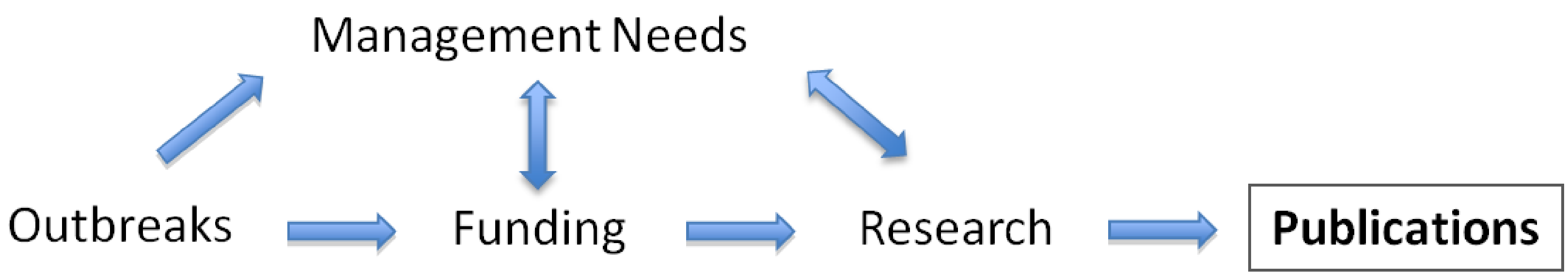

Figure 10. Potential pathways by which epidemic insect populations can lead to research publications.