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Wildlife Corridors: Do they facilitate biotic movement?
Evidence from the Experimental Literature

A Masters Thesis submitted in partial fulfillment of the requirements for the degree of Master of Natural Resource Management and Ecological Engineering (NRMEE)

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by
Lindsey Garven

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Abstract of a Masters thesis submitted in partial fulfilment of the requirements for the Degree of M.NRMEE

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Anthropogenic fragmentation of landscapes is a serious threat to wildlife habitats and the biodiversity of wildlife. To remedy this issue wildlife corridors have been implemented to mitigate the negative effects of fragmentation. Landscape manipulated to conduct corridor experiments have taken the initiative to answer the lingering question regarding corridor efficacy as movement conduits.

It is the aim of this thesis to investigate empirical evidence derived from published literature of experimental corridor research that evaluated corridor-dispersal function.

- *Conduct a review of "Experimental" corridor literature published over the last 17 years (1993-2010).*
- *Compare and contrast experimental variables including; methodological design, taxa studied, spatial and temporal scales as well as results.*
- *Create a methodology to identify quality scientific evidence of corridor-dispersal function.*
- *Examine the extent to which these experiments have contributed to nature conservation.*

A total of 28 documents were collected and reviewed. Research guidelines and the Ten Criteria for Experimental Documents were methods used to identify, collect and assess experimental corridor research for quality science. Two documents Haddad (1999) and Collinge (2000) were identified in presenting quality scientific evidence. Individual results from both Haddad (1999) and Collinge (2000) supported the efficacy of corridors through experimentation.

Trends identified from comparative analysis include limited experimental habitats, with 64% of studies being conducted in forested environments, 32% being conducted in grassland

environments and only 3% utilizing multi-landscapes. Methods most commonly used include mark-recapture-release (MRR), live trapping and vegetation sampling. Total experimental spatial scales ranged from 10-100 hectares for all studies and temporal range for consecutive studies averaged 18 months where as one-off studies ranged 14 months.

Contributions these studies have made towards nature conservation include advancements in monitoring methods, technology and increased species diversity with regards to land management, ecological restoration and stewardship and the evolution and diversification of corridor ecological research.

Acknowledgements

This dissertation would not be complete without the acknowledgement of several individuals who have greatly assisted me with this review. Firstly, I would like to express my sincere gratitude to my supervisors, Dr. Ian Spellerberg and Dr. Glenn Stewart, for their continuous support, guidance and patience throughout this study. Their scrupulous and persistent advice has enabled me to persevere through the confrontational challenges associated with scientific writing.

I also wish to gratefully thank Dr. Sharon Collinge, Dr. Brian Hudgens and Dr. Douglas Levey for providing me with information essential to for this research. In particular, I would like to thank Dr. Nick Haddad for bestowing me with valuable contacts. I also need to thank Dr. Tomas Carlo, Walter McCown and Ian Breckheimer for their prompt replies to my questions.

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I would like to thank my family, particularly my grandmother for financially supporting my continued education efforts, my parents and the rest of my family for their continuous support.

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1 Introduction

Habitat fragmentation and isolation are two of the most serious threats to wildlife, being directly linked to land use change associated with human development (Wilcox 1985; Wilcove 1996; Rosenberg 1997; Sala 2000; Ehrlich 2004; Hilty 2006) . Land alteration for agriculture, industrial and urban uses have resulted in the reduction and fragmentation of natural wildlife communities. This fragmentation effect separates wildlife communities and restricts animal movement. To remediate this issue wildlife corridors have been implemented into many landscapes.

Corridors, as defined by Lidicker et al. (1999) are any identifiable space that facilitates the movement of animals or plants over time, between two or more patches of otherwise disjunct habitat.

Interests in the concept and use of wildlife corridors have increased over the last three decades among conservation groups, ecological disciplines, policy makers and community planners. The concern lies in hopes to restore lost connectivity of habitat to facilitate the movement and conservation of biota. The exchange of varying genetic material between spatially distinct communities has a fundamental impact on ecological processes such as diversity-stability relationships, ecosystem function, and food web dynamics (McCoy 2009). Reduction of natural habitat leads to a decrease in species richness (Spellerberg 1993) which may potentially lead to homozygosity, genetic drift, inbreeding and a decreased ability for adaptation (Dawson 1994). Consequences of these occurrences may result in depletion of genetic variance within an area and can result in the extinction of a species.

1.1 Wildlife Corridors

The concept of wildlife corridors originated as a theoretical method to overcome habitat fragmentation. With practical application it became a conservation tool to reconnect habitat patches. Conservation biologists have speculated that connections between patches increased organism movement between appropriate habitats, ultimately increasing genetic material, species richness and the abundance of a population. Figure 1, demonstrates the broad conceptual corridor diagram, illustrating two otherwise fragmented habitats connected only by a linear strip. This concept is not limited to landscape or habitat type and may be applied in a multitude of spatial scales and configurations.

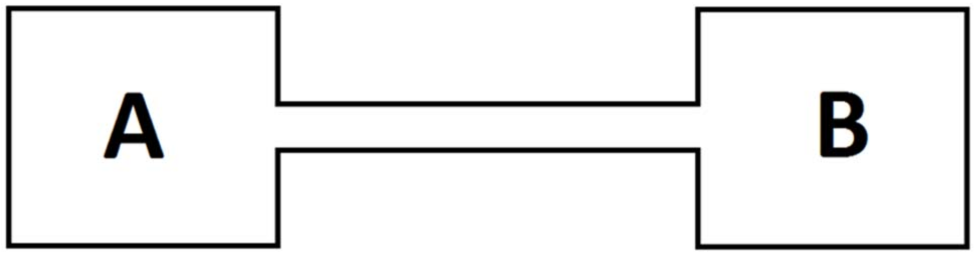

Figure 1 A broad conceptual corridor diagram. A & B represent patches connected by a linear corridor within a landscape.

While this concept may seem simple, multiple variables play into the functionality of wildlife corridors. Obtaining merit and credibility for functionality depends on the evaluation of such variables. Many variables directly influence the efficacy of a wildlife corridor for the purpose of facilitating species movement between two otherwise fragmented habitats. Such variables include but are not limited to; landscape type, edge effect, spatial scale and animal behaviour. Relevant variables must be considered when implementing a wildlife corridor to successfully achieve desired results.

Information regarding corridors and the influence of such variables (to determine species dispersal) is increasing but is still relatively theoretically based. Numerous corridor related studies state that solid evidence is lacking to either demonstrate or contradict these dispersal functions (La Follette 1982). For studies that take a more practical approach to answering the corridor-dispersal question, methodologies and quality of science require evaluation for credibility.

1.2 Research Aim

The aim of this research was to investigate empirical evidence derived from published literature of experimental corridor research that evaluated corridor-dispersal function. The four designated research objectives listed below were implemented to guide and direct this Masters thesis.

1.3 Research Objectives

1. Conduct a review of “Experimental” corridor literature published over the last 17 years (1993-2010).
2. Compare and contrast experimental variables including; methodological design, taxa studied, spatial and temporal scales as well as results.
3. Create a methodology to identify quality scientific evidence of corridor-dispersal function.
4. Examine the extent to which these experiments have contributed to nature conservation.

I hypothesize that I will locate more published experimental corridor literature that supports the corridor-dispersal function, opposed to literature that negates the function. This assumption was derived from the implementation of project corridors by land managers, conservationists and policy makers worldwide.

My second hypothesis is that less than half of the experimental corridor publications reviewed will successfully score ≥100% in my methodology, presenting little quality scientific evidence of corridor-dispersal function. This assumption resulted from the small selection of publications located for this review and the fact that corridor experimentation is a relatively new discipline, with the first corridor experiment initiated in 1993.

1.4 Thesis Limitations and Requirements

Peer reviewed scientific literature published within the last seventeen years (1993 -2010) is the target research timeframe for this review. Initially a fifteen year timeframe (1995-2010) was established for this Masters thesis, but as this review became more ‘specialized’ a decision was made to remove the time frame (of fifteen years) to include two relative pieces of literature published prior to 1995.

This research has been limited to only experimental corridor literature. Experimental corridor research is defined as experimentation that involves humans performing intervening actions such as a control or a manipulation of variables (generally landscape configuration) that directly assesses (falsifies or verifies) a stated hypothesis. In this context all of the reviewed literature have evaluated the dispersal function of corridors. Observational studies, transportation-design related corridor studies (e.g. structural wildlife over-pass and under-pass) and genetic modelling studies have been excluded. Literature accepted for this review was not constrained by geographic location or terrestrial landscape type. Aquatic and oceanic environments including estuarine ecosystems, as well as all micro-invertebrate corridor research have been excluded from this particular study.

2 Methodology

2.1 Literature Sources and Methods of Selection for Objective 1

Conduct a review of "Experimental" corridor literature published over the last 17 years (1993-2010).

Literature sources were obtained from online databases housed at Lincoln University. These databases included *Science Direct, Google Scholar* and *Web of Knowledge.* Other literary documents (books) were sourced from researchers in the field of Nature Conservation as well as referenced from other literature reviews and corridor documents. Literature searches were carried out in a systematic manner by identifying publications (journals) and conducting searches evaluating abstracts chronologically from 1993 to 2010. The journals with publications that are included within this study and the keywords utilized during online database searches are listed below.

Journals Researched	Key Words Searched
• *Biodiversity and Conservation* • *Biological Conservation* • *Biological Invasions* • *Conservation Biology* • *Ecological Applications* • *Ecology* • *Ecology Letters* • *Journal of Environmental Management* • *Landscape and Urban Planning* • *Landscape Ecology* • *Nature*	• Animal linkages • Animal movement pathways • Corridors • Dispersal conduits • Experimental corridors • Game trails • Invasion corridors • Wildlife corridors

Table 1 Listed journals and key search words

Specified key words were chosen based on terminology used to describe organism movement through a landscape connection that adjoined two distant and otherwise fragmented habitats.

2.2 Assessment of Experimental Research and Comparison of Experimental Variables for Objective 2

Compare and contrast experimental variables including; methodological design, taxa studied, spatial and temporal scales as well as results.

Following the identification of experimental documents that focus on species' movement via corridors; variables such as study taxa, experimental locations, experimental environments, temporal and spatial scales, methodological design and experimental results were organized on an Excel spread sheet for analysis.

2.3 Identification of Empirical Evidence for Objective 3

Create a methodology to identify quality scientific evidence of corridor-dispersal function.

Science is a methodological "quest" to present factual information that is an available resource to all. The institutional goal of science is the presentation and extension of certified knowledge. Knowledge is defined as empirically confirmed and logically consistent statement of regularities (Stemwedel 2008). Quantitative measurements have been emphasized in the scientific field as they provide a consistency brought about by the standardization of mathematics. Although used to make gross assessments, quantitative evaluations may lack well rounded perspectives (La Follette 1982) for specialized disciplines (such as corridor experimentation) and may restrict further progression.

For this study the evaluation of quality scientific evidence will occur through the use of a designed methodology (a set of 10 questions), created by myself, that evaluates experimental methodology and protocol for all corridor literature reviewed. To my knowledge there are no known methodologies that exist, that tests the quality of experimental corridor literature.

This methodology, a list of ten questions, is referred to as the Ten Criteria for Experimental Documents. These questions listed below have been applied to all experimental corridor literature reviewed and are explained in more detail below.

2.3.1 The Ten Criteria for Experimental Documents

1. Is the document's aim, objective and/or overall goal centered on species' movement through corridors?
2. Are confounding variables (variables that may negatively interfere with the end results) discussed?
3. Is a control or reference included?
4. Is experimental replication utilized?

5. Is statistical analysis used in the research?
6. Are limitations, errors or uncertainties discussed?
7. Are environmental conditions included in detail?
8. If habitat manipulation occurred, are target population parameters before and after habitat manipulation included?
9. Is relevant information on study taxa (e.g. Life History Traits) included?
10. Were the methods used to record movement of the studied organism recorded or inferred?

These ten questions were applied to all the experimental corridor literature reviewed for this study. With the exception of question 8 and 10, all other questions were answered with a 'yes' or 'no' answer. Questions answering with a positive response (yes) were awarded one point whereas negative responses (no) were neither scored a point nor had a point deducted. This method does not penalize studies that did not take extra initiatives but instead identifies and awards those studies that strived to conduct high quality research.

Limitations associated with this yes/no scoring system present all questions with equal "weight" or importance. For this Masters thesis I decided that all the variables included in the Ten Criteria for Experimental Documents be equally weighted for simplicity and for standardization. Future research may find this issue as a potential research gap in which I welcome further investigation.

The total amount of points a document could receive (excluding the bonus point, Question 8) was nine. Documents scoring nine or totalling 100% were labelled as a 'highly rated' document. Documents rating 77%-88% (7 to 8 out of 9 points) were rated as having 'medium quality' evidence and all documents with a percentage lower than 77% were rated as providing 'low quality' evidence.

2.3.2 The Ten Criteria

Variables included in the Ten Criteria for Experimental Documents were identified in the initial stages of this research and were refined as the research intent became more specialized (initial investigation included all corridor related research). The Ten Criteria was designed specifically for experimental corridor documents as many of the variables being assessed are directly tied to experimentation (use of a reference site and replication). Other variables were chosen by myself. It is my opinion that experimental corridor studies that provided more detailed information (limitations, environmental conditions and life history traits of study subject) give a clearer and more accurate description of the experimentation. This detailed information minimizes ambiguity and affirms merit and credibility for the study. Below, each variable of the Ten Criteria are discussed in more detail.

1. **Published Papers' Aims, Objectives and Overall Goals:**

The aims, objectives and overall goals are the cornerstone of the publication. These parameters guide and direct the progression of a paper and the investigation. If the investigation diverges away from the set parameters, it may not accomplish what was initially desired and thus may damage the document's credibility. I felt it important to examine each document's aims, objectives and overall goals to see if these stated variables coincided with species' movement through corridors and did not diverge and evaluate other related or side topics such as edge effect or stepping stones. It was also important that the literature answered the questions it initially set out to explore. Documents with aims, objectives and overall goals corresponding with the above mentioned variables, received one point.

2. **Addressing Confounding Variables:**

Confounding variables may be considered as variables that researchers fail to control or eliminate, which may result in influencing the end results and therefore the 'credibility' of an experiment. The discussion of confounding variables is an acknowledgement of the author's performance of an evaluation of external variables (uncontrollable/ controllable) that may influence the study and interfere with scientific interpretation and the analysis of data obtained from experimental studies. The lack of recognition of confounding variables may invalidate a scientist's work, reflecting poorly upon the author(s) and may result in questionable scientific integrity.

Authors should be encouraged to address confounding variables and mitigate the issue if possible. For example Berggren et al.(2002) discussed the avoidance of one variable confounding study design, the influence of an insect's directional flight path. To overcome this potential confounding issue, researchers released insects from an open palm facing each cardinal direction an equal number of times. Documents that directly addressed confounding variables received one point.

3. **Utilization of a Research Control :**

A control or reference is any variable that is controlled, kept natural or isolated by the researcher for comparison purposes. Controls may also be used to provide baseline data and are essential in the design methods of an experiment. For example, four control sites were used by Coffman et al. (2001) as unfragmented habitat as well as previously used for data collection prior to experimentation. Unlike observational studies, experimental studies have the advantage of utilizing controls which assist in testing a hypothesis. The intent of this question was to identify experimental studies that incorporated reference sites into their experimental design. Documents that included such reference/ control sites were awarded one point.

4. **Utilization of Experimental Replication:**

Replication is an important attribute for any scientific experiment. Replication in regards to experimentation is necessary to estimate the imprecision or random error of the analytical method (Westgard n.d.). It can also serve to increase the confidence in an experimental result or outcome. Hence unreplicated studies are regarded as carrying "less value" as there is no evidence of consistency among trends or results. It is pertinent that an experiment be replicable for testing reasons. For example, Baum (2004) demonstrated this by enlisting 20 replicate experimental sites. This was made possible by the spatial scale of the experiment, with the total area of each site measuring less than $50m^2$. With 20 replicate sites, Baum (2004) was able to increase the data collected from each experimental trial. This would have helped the experimental data analysis to be more robust. Documents reviewed for this study were allocated one point for their use of replicated experimental sites.

5. **Utilization of Statistical Analysis:**

Statistics as defined by Dodge (2003) is the study of the collection, organization and interpretation of data. Within the scientific field the use of statistical analysis is also used to make comparisons, identify reoccurring trends, and test for significant differences between data sets. For example, in Fried et al. (2005), the researchers explicitly use a particular statistical model (post-hoc with Bonferroni correction) to test their data with both the 'Traditional Corridor hypothesis' and the 'Drift Fence hypothesis'. Details of these hypotheses may be found in Fried et al. (2005). The results of both models significantly supported the two hypotheses. In experimentation, statistics is seen as a requirement for producing 'credible' scientific results. Documents scored one point for their use of statistical data analysis.

6. Statement of Methodological Limitations and Other Limitations:

Methodological limitations are conditional boundaries for the experimental design or protocol. These may include but are not limited to; time, money, resources, policies, writing style and available knowledge in the field of study. One example of a methodological limitation is the alteration of methodological techniques. This was the circumstance for Danielson & Hubbard (2000) where it was necessary for them to change their nest box design halfway through their experiment. This unfortunately restricted the comparison of data between the two years. Other limitations are restrictions (writing style, errors, uncertainties and deleted or ignored data sets) that apply to other aspects of the experiment such as the experimental outcome or results, as well as the publication. With varying writing styles among individuals a document has the potential to be limited by the author's ability to discuss clear significant interactions, analytical interpretations or implications of the study. Clarity among scientific literature is emphasized as it increases the knowledge base of the reader and increases the credibility of the work. Documents stating any limitations were given a score of one point.

7. Discussion of Environmental Conditions:

With experimental corridor studies, I consider environmental conditions (surrounding vegetation, topography, weather patterns, etc.) to be a relevant variable especially when habitat manipulation is scheduled to occur.

There are many unknown variables linked to ecosystem functionality, which alterations (e.g. habitat manipulation) may result in new and unknown ecological changes. Collecting such available information prior to habitat manipulation may assist with the investigation and understanding of future potential interactions.

For example, Söderström & Hedblom (2007) went into great detail when addressing environmental conditions (wind speed, temperature and humidity) that had the potential to affect the movement patterns of the study subject. They also discussed the various vegetation types and microhabitats that would ultimately affect the behaviour of the study subject. With experiments of this nature it is my opinion that all documents should clearly state environmental conditions. Documents that failed to describe experimental site description (vegetation type, climatic conditions, etc.) received no point where as documents that successfully stated conditions were allocated one point.

8. **Habitat Manipulation & Target Population Parameters:**

If habitat manipulation occurred, did the document include any recorded data of target population parameters before and after habitat manipulation?

Movement parameters (events or effects that are a catalyst for movement) and parameters of target populations (detailed description of a population within an area) give researchers a general understanding of variables that may be contributing to the circumstances and constraints that a specific population is under.

This information can assist researchers with designing their experimental methods and provide baseline data of a target species prior to the experiment which allows for comparisons afterwards. The Calling Lake experiments (Machtans, Villard et al. 1996; Schmiegelow, Machtans et al. 1997; Hannon and Schmiegelow 2002) are most notable for conducting pre-habitat manipulation assessments. Their studies consisted of mist netting birds to gather information on species' richness, species' abundance, density, age and sex of all birds captured.

This question was allocated as a bonus question. It is my opinion that studies that conducted pre-habitat manipulation assessments should be awarded a point for their premeditative methodological design. If studies did not manipulate the habitat or if studies used trans-located subjects, those studies were deemed as non-applicable for this question. Studies monitoring resident subjects would be applicable for this question (as they had the option to collect data on species population parameters) upon which they either have answered 'yes' and received the bonus point, or 'no' and did not receive any additional point.

9. **Life History Traits :**

Life History Traits provide information about species-specific characteristics such as:

- Multiple life stages
- Breeding and feeding behaviors
- Anthropogenic habitats
- Anatomical features and functions

These are central elements to consider when developing an experimental methodology. If overlooked, these characteristics may develop into confounding variables or limitations, reducing scientific quality of the experiment.

Rosenberg et al. (1998) for example discussed the life history traits of their study subject *E.eschscoltzii*, such as suitable habitats, inland terrestrial span, movement behaviours and the differences between males, females and juveniles. These variables assisted with the methodological design and protocol of the experiment. It's worth noting the importance of changing life stages of differing study species and how these life stages may influence individual and population responses to experimental corridor studies (Haddad 2006). Documents that directly stated the use of life history traits received one point.

10. Inference vs. Recorded Evidence:

The final question investigated if species' movement through a corridor was recorded or inferred. Studies were identified and labelled as either 'recorded' or 'inferred' based on methodologies used to identify species' movement through corridors.

'Recorded' studies obtained results about species' movement from accurate information or data. Recorded data may take many forms, from visual observation accompanied by recorded measurements to the use of technological recording devices. For example Castellon & Sieving (2006) employed radio telemetry and GPS to closely track the exact locations and movement pathways of each study subject.

'Inferred' studies derive conclusions about species' movement on the basis of partial or limited information. These include studies that attribute corridor efficacy (as a movement pathway) from population parameters (abundance, species' richness and density) of the study taxa.

The Calling Lake experiments (Machtans, Villard et al. 1996; Schmiegelow, Machtans et al. 1997; Hannon and Schmiegelow 2002) used bird counts to study the effect of fragmentation that ultimately made inferences about the corridor-dispersal patterns of various avian species.

In my opinion, recorded information is more reliable because research methods strive to provide solid evidence of species movement. The use of technological tracking methods (such as radio tracking) lowers the range of error compared to studies that infer species movement from population parameters. Therefore studies that were labelled as recorded were allocated one point whereas inference studies were neither rewarded or deducted a point.

2.4 Contributions Towards Nature Conservation for Objective 4

Examine the extent to which these experiments have contributed to nature conservation.

Chapter 5 will focus on the outputs of experimental corridor research; particularly evaluating research advancements that have directly influenced conservation efforts. Authors of experimental corridor documents (those studies that scored 100% from the Ten Criteria) were contacted and interviewed about implications of their results for nature conservation.

This chapter will also include an historical perspective on wildlife corridors, experimental corridor research and will briefly acknowledge the other corridor disciplines (Observational studies, transportation-design related corridor studies and genetic modelling studies) and their relevance in the 21st Century.

3 Historical Framework

3.1 Introduction

This section will briefly discuss corridor publications that have influenced ecological studies of corridors, habitat fragmentation, and edge effect along with connectivity through corridors.

3.2 'Keystone' Publications in Corridor History

This section was included to address 'Keystone' publications. I define 'Keystone' publications as literature that established the foundation of or influenced the development of corridor research. I consider these publications to be of high value for their original theory, practical application or results. I believe they have helped form scientific norms associated with wildlife corridors, species movement in fragmented landscapes and research methods. I have found that these publications are often cited in newer literature and therefore are associated with having a high citation number. It is important for readers to understand the progression of corridor research and the successive order these events occurred to comprehend the steps forward that experimental corridor research has made over the last 17 years. Figure 2 is a timeline of these 'Keystone' publications.

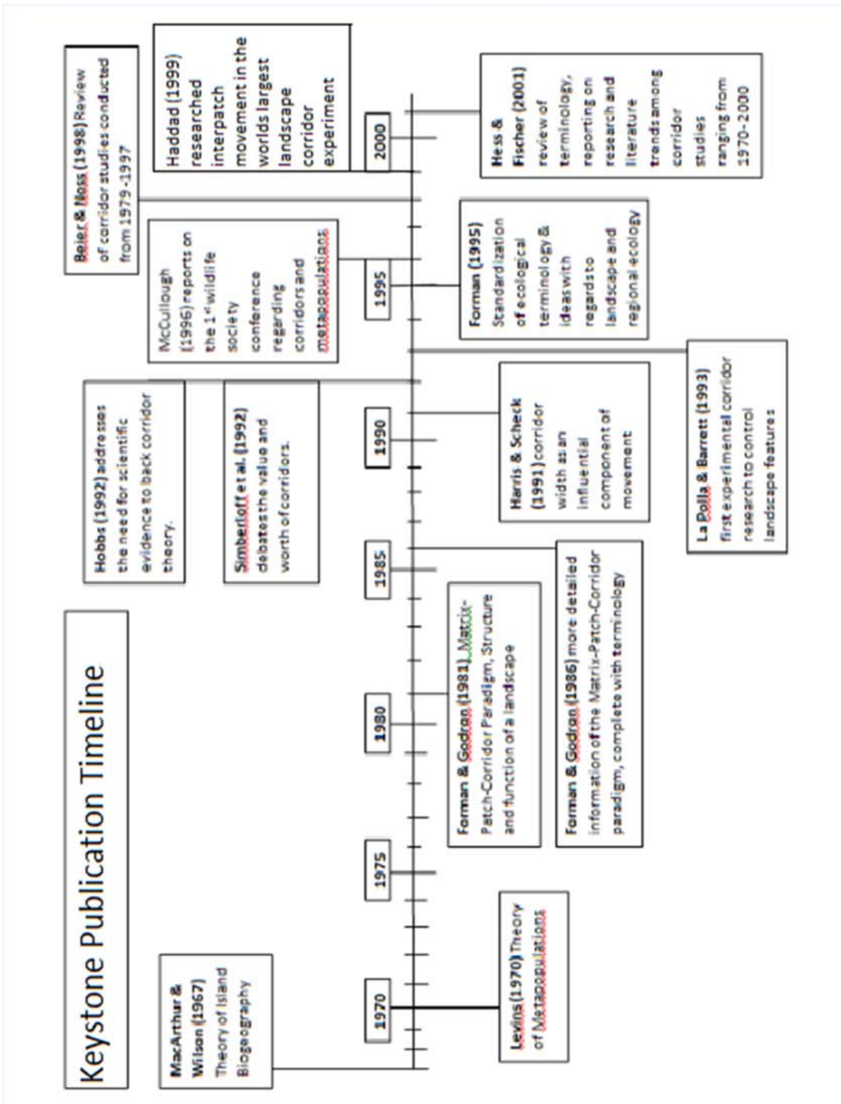

Figure 2 Timeline of 'Keystone' publications

- Forman & Godron's (1981) publication was a detailed analysis of landscape configuration, successional patch dynamics (relating to disturbance ecology) and the introduction of the patch-corridor-matrix paradigm. By examining aerial photographs, Forman & Godron (1981) were able to visually identify the different landscape features of heterogeneous and homogenous areas. From this, researchers conceptualized structural landscape attributes, corridor, patch and matrix area. Prior to the introduction of this paradigm, researchers investigating corridors and faunal movement didn't consider landscape composition to be an influential variable in corridor function. [Cited 520 times as of December 2012]

- The book *Landscape Ecology* by Forman & Godron (1986) further expounded on the corridor-patch-matrix paradigm and the progression of the land mosaic paradigm. This publication provided a more detailed terminology, landscape typology, natural processes as well as human roles in the origin of landscapes, and information theory analyses of landscape heterogeneity(Forman 1995). Landscape ecology works on a large spatial scale and requires the use of aerial photography, Global Positioning System (GPS) and Geographical Information System (GIS) to evaluate such large landscape configurations. This research has developed and better defined the discipline of Landscape Ecology.

- Another influential step towards the evolution of corridor research was Harris & Scheck (1991) with their research on the correlation between corridor width and animal dispersal. Harris & Scheck (1991) stated that width of faunal corridors need to be appropriate to the scale of the phenomenon being addressed and to the size of the ecological function being asked. A very important variable that should be considered and evaluated prior to the implementation of wildlife corridors.

- 1992 marked two distinguished publications, Simberloff (1992) and Hobbs (1992). Both authors challenged the corridor-dispersal concept by suggesting that corridors did not facilitate species movement. Simberloff (1992) discussed the negative effects (ecological and financial) of implementing corridors as well as addressed the lack of scientific evidence to support the use of wildlife corridors as movement conduits. Hobbs (1992) also questioned the role of corridors as movement conduits. He made a compelling statement by which the corridor-dispersal function could not be determined without stronger scientific evidence to back the concept. These two publications are valued for their controversial position. They have set the standard for scientists who seek to answer the corridor-dispersal inquiry. [Simberloff (1992) cited 605 times as of December 2012] [Hobbs (1992) cited 300 times as of December 2012]

- La Polla & Barrett (1993) conducted the first corridor experiment by monitoring vole dispersal through a small scale fragmented landscape. By manipulating landscape features researchers controlled the length and width of the corridors as well as the size and shape of the habitat patches. Results from the study concluded that male voles dispersed more frequently than females and that corridors did facilitate more male voles than patches without corridors. [cited 120 times as of December, 2012]

- In Forman's(1995) book *Land Mosaics*, he discusses past information addressed in Forman & Godron (1981; 1986) as well as expounded on various land mosaic types (including types of corridors), species movement through mosaics and also addressed potential conservation initiatives such as land planning and management and the creation of sustainable environments.

- McCullough (1996) reports on the first meta-population and wildlife conservation symposium held in Albuquerque, New Mexico in September of 1994. The number of attendees, speakers, and interested body set a precedent of the growing discipline of meta-population ecology and how land mosaic influences species populations. The symposium is an indicator to scientists of the growing concern for habitat fragmentation and wildlife conservation.

- Beier & Noss' (1998) publication *Do habitat corridors provide connectivity?* conducted a review of both experimental and observational corridor research. This was the first publication to evaluate experimental corridor research. The study investigated how wildlife corridors affected population viability of species. After reviewing 28 corridor publications the authors concluded that most documents were limited by design flaws confounding the interpretation of the results. Less than half the documents reviewed provided evidence to support corridors as a conservation tool. Beier & Noss (1998) emphasize the value of addressing confounding variables, repetition and stating life history traits. [Cited 802 times as of December 2012]

- Haddad's (1999)(1999) publication *Corridors and Distant Effects on Interpatch Movements: A Landsacpe Experpriment with Butterflies* is the first of many corridor-dispersal studies conducted in a landscape scale corridor experiment, with a total of 27 patches each measuring 1.64 ha. It is currently the world's largest replicable corridor experiment. Haddad's corridor design differs with others in that he monitors insects in such a large spatial scale. The experimental design is also novel in that the patch and corridors are comprised of early successionary vegetation with the matrix consisting of pine forest. Most other corridor experimental designs used the inverse for patch-matrix-and corridor. [Cited 210 times as of December 2012]

- Hess and Fischer (2001) publication *Communicating clearly about conservation corridors* is an overview of terminology and definitions used in corridor publication. Hess and Fischer(2001) bring to light the many names, functions and forms of wildlife corridors in an effort to instill understanding and guidance for landscape planners or those involved with the creation of corridors. They identify the misinterpretations and help standardize the discipline of corridor ecology. [Cited 99 times as of December 2012]

From the 1960's and early 1970's, two influential theories were developed. One was the Theory of Island Biogeography and the other was the Theory of Metapopulations. MacArthur & Wilson (1967) published their Theory of Island Biogeography, which evaluated the distribution and evolution of organisms on remote oceanic islands with emphasis on species richness as a dependent variable to the immigration and extinction equilibrium. This theory was later misapplied to one aspect (species area relationship) of the theory. Researchers applied SAR to non-isolated "island" habitats that were surrounded by inhospitable landscapes.

Metapopulation ecology is the study of discontinuous populations distributed over spatially incoherent habitat patches that are divided by inhospitable habitat (matrix). The high risk of mortality associated with crossing the matrix affects dispersal of individuals between patches (McCullough 1996). This theory was introduced in 1970 by the mathematical ecologist Richard Levins. Within the field of metapopulation ecology, there are two alternate philosophies of interpreting the consequences of habitat fragmentation as it relates to genetic flow and species survival.

This barrier effect (generally in reference to roads that fragment habitats and inadvertently create a barrier to species movement) directly affects the longevity of a population residing within a patch as population size is generally dependent on patch size. In instances where small patches do not receive new genetic material local extinction may occur. This event may be followed by a recolonization of another population of the same or new species (McCullough 1996).

Metapopulation ecologists and conservation biologists are in disagreement about the effects of isolation. Metapopulation ecologists have the view that isolation is a natural element of landscapes, whereas conservation biologists regard this ideology as problematic (Rosenberg 1997; Beier 1998; Hanski 1998; Townsend and Levey 2005). The division of habitat into patches which are surrounded by inhospitable habitat conditions (matrix) is often referred to as habitat fragmentation.

3.3 Habitat Fragmentation

Habitat fragmentation may be defined as the transformation of a continuous habitat into habitat patches that vary in size and spatial configuration (Fahrig 2003; Hilty 2006). Fragmentation can result from both natural and anthropogenic disturbances. Natural disturbances attributed to habitat fragmentation include but are not limited to flooding, tornados, fire, avalanche, rock fall and debris flow. Although these disturbances may cause habitat fragmentation, they are a part of the evolutionary process and initiate succession to occur. Anthropogenic disturbances such as deforestation for timber, clearing of land for agriculture and urbanization permanently alter the land and prohibit natural successionary events. Collinge (1998) lists four main types of anthropogenic fragmentation; shrinkage, bisection, patch fragmentation and perforation, which are each unique in their configurations (Figure 4).

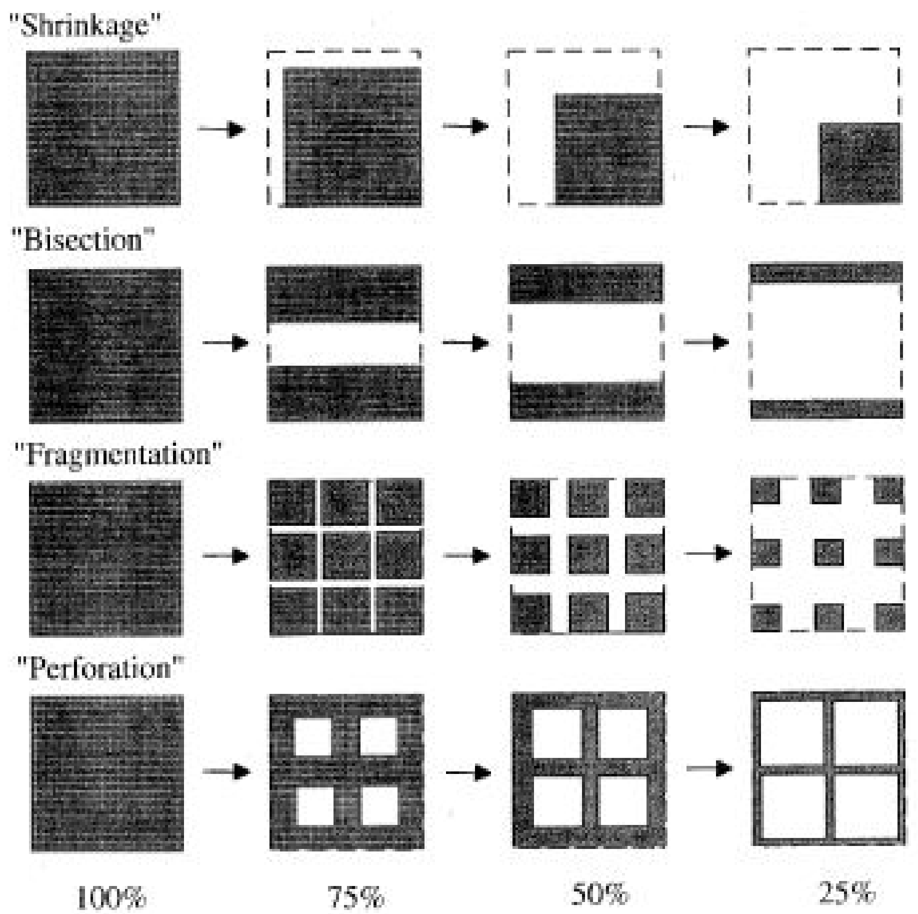

Figure 3 Collinge's (1998) Conceptual model of four fragmentation patterns.

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hrinkage has been defined as a progressive reduction in size and area. This form is particularly common in both agricultural and forestry landscapes.

- Bisects are the division of an area into two physically separate entities, generally seen with road and highway development.
- The division of initial landscape into patches is patch fragmentation.
- The removal of patch habitat or the expansion of developed landscape outwards in size is known as perforation, generally a fragmentation pattern of urbanization (Collinge 1998)

Humans have altered land mainly for agricultural purposes, industry and for urbanization. In several cases, fragmentation leads to insularization or isolation of a habitat as well as its resident species.

Figure 5 demonstrates the gradual insularization of a forested area by anthropogenic development over time. Different effects on species populations occur under each of the fragmentation types. As displayed in figure 4, patch fragmentation for example will lead to smaller individual patches than habitat shrinkage would. These smaller patches hold smaller quantities of resources and therefore restrict the quantity of individuals in a population that are able to inhabit a patch. Although it is debatable whether smaller patches are more resilient than larger patches. Another inconsistent characteristic that results between the four habitat fragmentation types is the distance of edge effect that is relative to each fragmentation type.

Figure 4 Urban sprawl induced Insularization. Photo taken from Planning Communities Florida Habitat website at http://floridahabitat.org/wildlife-manual/planning-communities retrieved December, 2011.

3.4 Edge Effect

Edge effect is referred to as the abrupt transition between two distinctly contrasting adjoining habitats that may be comprised of differing community types (Forman 1995). An example of an edge effect would be the contrast of a pine forest adjacent to a recently clear cut area of forest, delineated with a sharp edge between habitats. There is more edge effect associated with patch fragmentation than there is with habitat shrinkage. Commonly, natural landscapes change gradually from one ecosystem to another. Referred to as ecotones or ecozones, this area is generally diverse in species as it is the transitional zone where two differing ecosystems “blend” together (Hilty 2006).

Negative effects associated with edges include incursion by invasive species, a decrease in suitable habitat for patch dwelling species and the alteration of microclimate along the perimeter edge of the patch habitat.

Considered problematic by ecologists and conservationists, invasive species may be defined by their opportunistic capabilities to invade landscapes and out-compete niche specialist species, resulting in decreased species richness and a more homogenous landscape (Hilty 2006). Another negative effect attributed with edge induced fragmentation is the speculation that areas with far-reaching edges are not utilized by interior patch dwelling species (generally habitat specialist species). This ultimately decreases habitat and population size of patch specialists resulting in such problems as inbreeding, homozygosity, a lessened ability to adapt, and a reduced species richness, abundance and niche availability (Hilty 2006). Lastly, areas with far-reaching edges have an increased exposure of edge habitat to natural elements such as wind, rain and sun light. Studies evaluating microclimates within habitat patches have found that increased edges reduce microclimate humidity resulting in drier soils, changes in microbial community structure, a decrease in nutrient content and perhaps nutrient availability (Hilty 2006).

3.5 Connectivity via Corridors

Connectivity is the ability to make and maintain a connection between two or more points. In nature conservation, corridors have generally been created, maintained or restored to mitigate the negative effects of habitat fragmentation, although their purposes are not limited to just connectivity. Wildlife corridors have been employed as a management tool for faunal movement by wildlife managers since the early 20th century (Hess 2001). Since then, corridors have gained popularity throughout many disciplines (ecology, conservation biology, landscape planning, etc.) and have acquired many names, functions and come in several different shapes and sizes. Table 2 was selected from Hess & Fischer (2001) and displayed here to demonstrate the multiple names, functions and shapes associated with corridors.

Names, Functions and Shapes of Corridors		
Names	**Functions**	**Shapes**
Corridor reserve Conservation corridor Dispersal corridor Ecological corridor	Conduit Habitat Barrier Buffer	Linear – strait Curvilinear Vegetative riparian strips along a stream or river

Faunal dispersal corridor Greenway corridor Habitat corridor Landscape corridor Landscape connection Line or Strip corridor Landscape Linkage Riparian corridor Remnant corridor River or Stream corridor Wildlife corridor	Filter Source Sink Aquatic nutrient sink For land and soil stabilization reasons Cultural & Recreational area Area for societal use Barrier to development	Highway under & over passes Trail systems Wind breaks Live (vegetative)fencing, Hedgerows Linear power line strips Highway grassland strips

Table 2 Names, Functions and Configurations of Corridors as stated by Hess & Fischer (2001)

It should be noted to readers that terminology, function and configuration can range diversely. For example the term greenways is “linear vegetated networks” acquired and maintained mainly for recreational use by the public (Fabos 1995). Although multifaceted in function, greenways also serve to conserve land and natural resources, establish boundaries for urban sprawl and provide the public with aesthetic recreational pathways. Some examples of well-known North American Greenways include the Appalachian Trail (AT), Pacific Crest Trail (PCT), Continental Divide Trail (CDT) and the Trans Canadian Trail.

As a greenways primary purpose is directed towards societal recreation, there is potential to create human-faunal interface issues in the corridor context, resulting in either a source (actions or events which result in the production of a species) or a sink (action or events which involves the removal or extinction of a species) function.

An example of a source function would be the increase in birds and insects throughout greenways, as the birds feed on the increased insect populations that are attracted by the presence of humans. Thus this positive feedback has potential to benefit both conservation and recreational aspects of greenways.

As for the latter, a sink function (generally negatively associated) can arise when human presence occasionally attracts potentially dangerous wildlife. Artificial feeding of wildlife (both intentional and unintentional) by humans, has great potential to create dangerous situations for both humans and wildlife. Studies and past experiences have shown that human feeding interferes with normal animal behavioural patterns, causing increased aggressive behaviour of animals towards humans (e.g. bear attacks on humans). Other concerns that are associated with artificial feeding include the spread of disease and the interference in food web processes (Heiser 2003).This is why conservationists, land managers and landscape planners must be vigilant when designing a greenway.

In summary, this chapter has addressed 'keystone' publications that have influenced corridor ecology by establishing a foundation for others to build from. Discussion of the Theory of Island Biogeography and the Theory of Metapopulation led to a detailed explanation of habitat fragmentation, edge effect and connectivity through corridors.

4 Review of Experimental Corridor Research

4.1 Introduction

This chapter addresses objectives 1, 2 and 3. The first section evaluates the processes required to conduct this particular literature review (objective 1). The second section (Results and Overview) will report the findings of individual studies (one-off studies) and consecutive studies, as well as compare experimental attributes such as geographical locations, experimental environments, taxa studied, spatial and temporal scale and methodologies used (objective 2). The final section of this chapter will address the methodology used for the third objective (The 10 Question Criteria) as well as report the results of the document analysis (objective 3).

4.2 **Addressing Objective 1** - *Conduct a review of the most recent "Experimental" corridor literature published over the last 17 years (1993-2010).*

As stated in Chapter 2, methodology, literature was extracted from online databases in a systematic manner. Literature compiled for this review consisted of documents that fell into the 17 year window spanning from 1993-2010 and included all terrestrial studies conducted worldwide. Originally this thesis was designed to appraise a variety of different types of published corridor documents to compare and contrast study components and to identify scientific evidence that supports or negates the efficacy of corridors as a facility for movement. Initially a total of 121 corridor documents were assessed and accepted for this literature review. Upon investigation of the selected corridor literature it became necessary to categorize the different types of corridor documents for organizational purposes. A total of four categories were identified: as observational, experimental, transportation-design related and genetic modelling studies. Figure 5 lists the definitions of these four categories accompanied by examples.

Observational studies utilize the ability to make direct observations of a study subject in order to make inferences about a possible treatment and its effect on the subject. For this study, all collected literature reported observing species movement through natural corridor environments. All studies were void of human interference and were listed as observational. Osborn & Parker (2003) visually observed and recorded (from a distance) elephant herd movements through a migration corridor in Zimbabwe.

Experimental studies are those that involve humans performing intervening actions such as a control or manipulation of variables (generally landscape configuration) that directly assesses (falsifies or verifies) a stated hypothesis. Townsend & Levey (Rosenberg 1997; 2005) monitored plant pollen movement by insect transport through human-created corridors to test both the Corridor Hypothesis and the Drift Fence Hypothesis.

Transportation-design related studies (generally observationally based) are those studies that evaluate a subject's behaviour in relation to a man-made object or structure (highway over-pass or under-pass) that facilitates the movement of the study subject. Clevenger & Waltho (2003) conducted a study assessing wildlife crossing structures implemented into the Trans Canadian Highway. The study installed tracking sections beneath designated underpasses to identify species that utilized the crossing structure.

Genetic modelling studies (generally observational based) are those studies that specifically monitor species movement through the evaluation of genetic variance. The assessment of a subject's cellular material is necessary for this type of study, which may require human interference. Dixon et al. (2006) identified kinship between bear populations as well as 23.54 tracking black bear movements through a natural corridor from

Figure 5 - Four Corridor Categories

To fulfil the third objective for this thesis it was necessary to construct a methodology that could be applied across all corridor practices. The process of designing such a methodology became flawed with skewed questions that applied to only some practices and resulted in a complicated scoring system. In order to achieve my established aim and objectives I decided to specialize on experimental corridor studies. This decision would allow me to investigate experimental corridor literature more thoroughly. I chose experimental corridor studies because it gives direct and controlled results and in my opinion has greater implications towards future development in computer modelling. Benefits of modelling systems may provide opportunities that test unknown mechanisms linked to ecological processes at landscape levels that would otherwise be difficult to test (Rosenberg 1998).

4.3 Addressing Objective 2 – *Comparisons and contrasts of experimental variables from the reviewed literature.*

4.3.1 Results of Study Locations & Environments

Of the 28 publications examined for this review, the majority 96% of the studies were conducted in the Northern Hemisphere, particularly within the United States, Scandinavia and Canada. The only study conducted in the Southern Hemisphere took place in Chile. The majority of the studies (19 of 28) were conducted within the United States, with 74% of studies conducted at the Savannah River Site (SRS) in North Carolina. All other states were sites to one off studies, also referred to as independent studies and together make up the other 26%. Norway and Sweden made up 18% of the study locations with 3 studies hosted at the Evenstad facility in Norway and 2 independent studies conducted in Sweeden. Canada hosted all their studies in Alberta at the Calling Lake facility. The two most frequently used environments were forested areas and grassland ecosystems. Studies within grassland environments include those conducted in Scandinavia and some from the USA. Studies conducted within forested areas include those at Calling Lake in Alberta (Canada), the SRS site in North Carolina (USA) and an individual study conducted in Oregon (USA). Only 1 study was conducted in multiple environments, and included rainforest ecosystems, agricultural areas and landscapes consisting of secondary growth.

4.3.2 Results of Spatial and Temporal Scale

Spatial scales were examined at two levels, source patch area and total experimental area. Since corridor experiments share a common design (two or more patches connected by a corridor and surrounded by matrix area) I felt it necessary to assess and compare the spatial scales at two levels; one that evaluated the total experimental area and the evaluation of the source patch area in which the study subject was released from.

Source patch (sample size 25)	
Category	Range
C1	0-1 m^2
C2	2-100m^2
C3	101-1,000m^2
C4	1,001-10,000m^2
C5	10,001-100,000m^2

Figure 6 Source patch spatial range

Of the 28 publications that were reviewed only 25 of the studies were evaluated for source patch area. Three studies (Calling lake citations here) were excluded as they had multiple sized source patches, that were not standardized in area. All source patch area were organized into categories dependent on range. Figure # demonstrates the ranges. Over half of the studies (84%) fell between C3 and C5, with C3 averaging at 24%, C4 at 32% and C5 with 28%. When evaluating the area in hectares 44% of all source patch areas were less than one hectare (<1ha), where as 28% of the studies we both equal to one hectare and also greater than one hectare(>1ha).

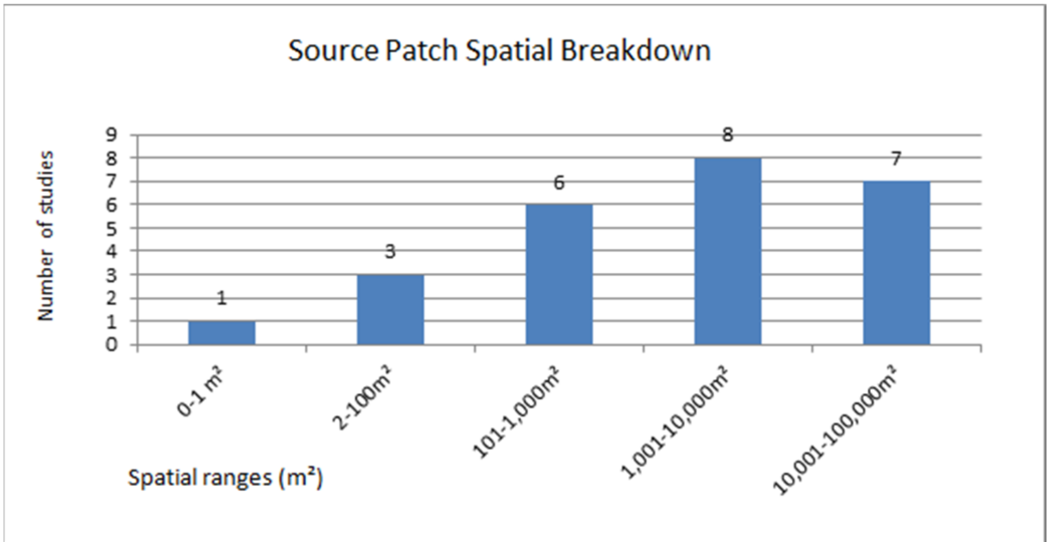

Figure 7 Source patch spatial breakdown

Total experimental (sample size 27)	
Category	**Range**
C1	0-1,000m^2
C2	1,001-10,000m^2
C3	10,001-100,000m^2
C4	100,001-1,000,000m^2
C5	1,000,001-10,000,000m^2
C6	10,000,001 - 150,000,000m^2

Figure 8 Total experimental spatial range

For total experimental spatial area, only 27 publications were evaluated. Bergren et al. (2002) was excluded as there was no spatial information listed for total experimental area. A similar protocol was performed categorizing publications by range. An extra range set (C6) was included for the three Calling Lake Studies (11%) that conducted their research in a very large experimental area.

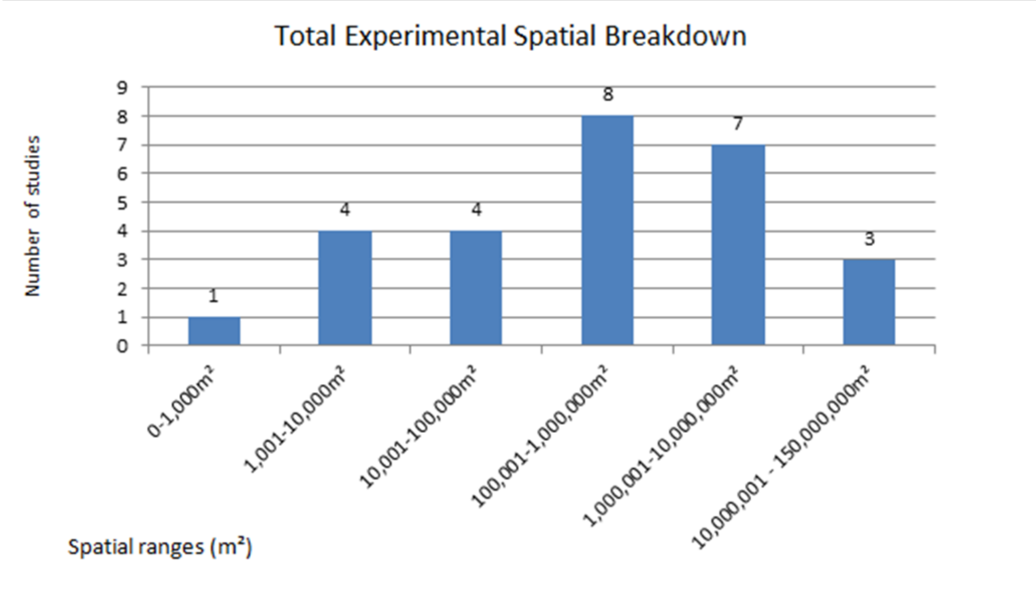

Figure 9 Total experimental spatial breakdown

Category 4 was the most utilized range with 29%, followed by C5 at 25%. Categories 2 and 3 both averaged 15% and C1 with the smallest value of 4%. Upon evaluation of these studies in terms of hectares, 11% of studies ranged greater than 1,000 ha, 26% of the studies averaged 110 ha, while another 26% of studies averaged 50 ha. Studies that ranged less than 50ha were valued at 34% with 18.5% of that value designated to studies that measured less than 1 ha.

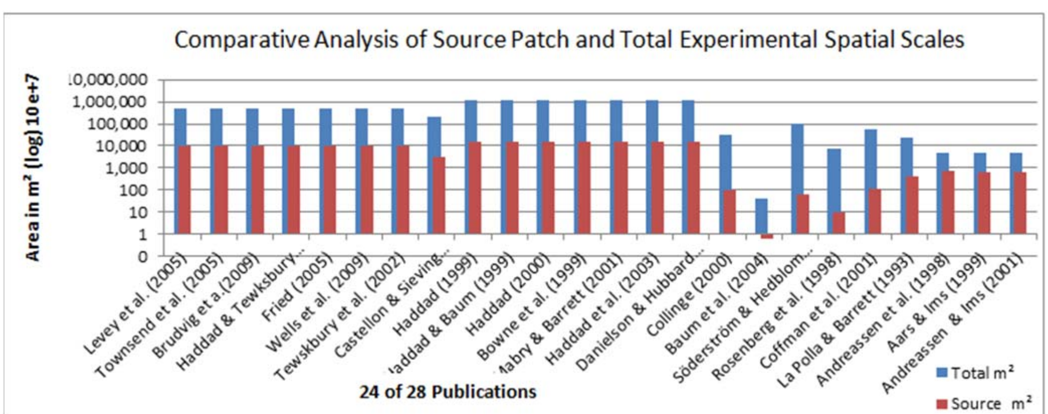

Figure 10 Comparative analysis of source patch and total experimental spatial scales

Figure 12 presents a comparison between the total experimental area and the source patch area of 24 out of the total 28 studies reviewed. The experiment with the smallest spatial scale was Baum et al.(2004) with a source patch of 0.58m² and an experimental area of 39.4m². The largest spatial scale were the Savannah river site experiments (particularly those conducted at the first site, from 1999 to 2003) with a total experimental area of 110 hectares (1,100,000 m²) and source patches with an area 1.6 hectares (16,384m²).

Figure 13 demonstrates the varying spatial scales of the landscape features utilized by the Calling Lake publications. The study design incorporated multiple sized patches, (both connected and isolated) but considering the study taxa consisted of resident species that were not released from a particular area, these studies were excluded from source patch spatial breakdown (figure#) and the comparative analysis graph (figure3). Isolated patches came in sizes of 1, 10, 40, and 100 hectares, where as connected patches only consisted of 1, 10, and 40 hectares.

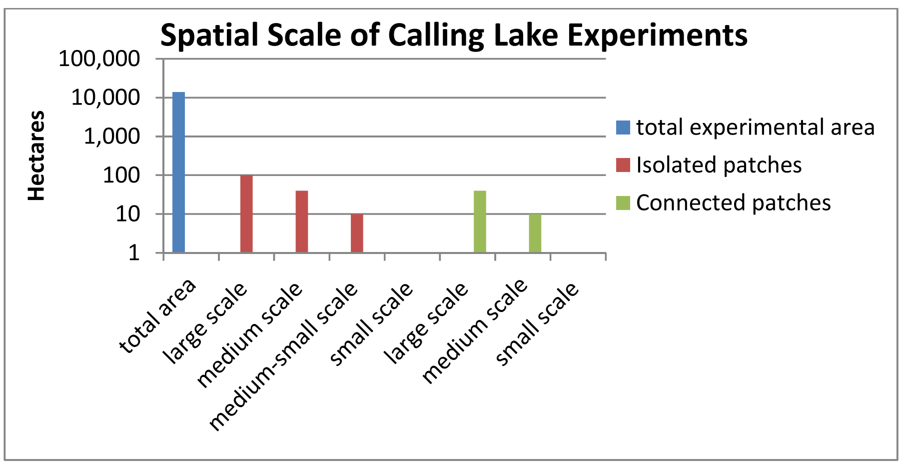

Figure 11 Spatial scale of Calling Lake experiments

4.3.3 Results of Temporal Scales (dimensional)

Of the 28 experimental corridor studies, 12 studies were conducted from 1993 to 2000, 12 studies from 2001 to 2005 and the remaining 4 documents from 2006 to 2010. Figure 14 shows the timeline of these studies.

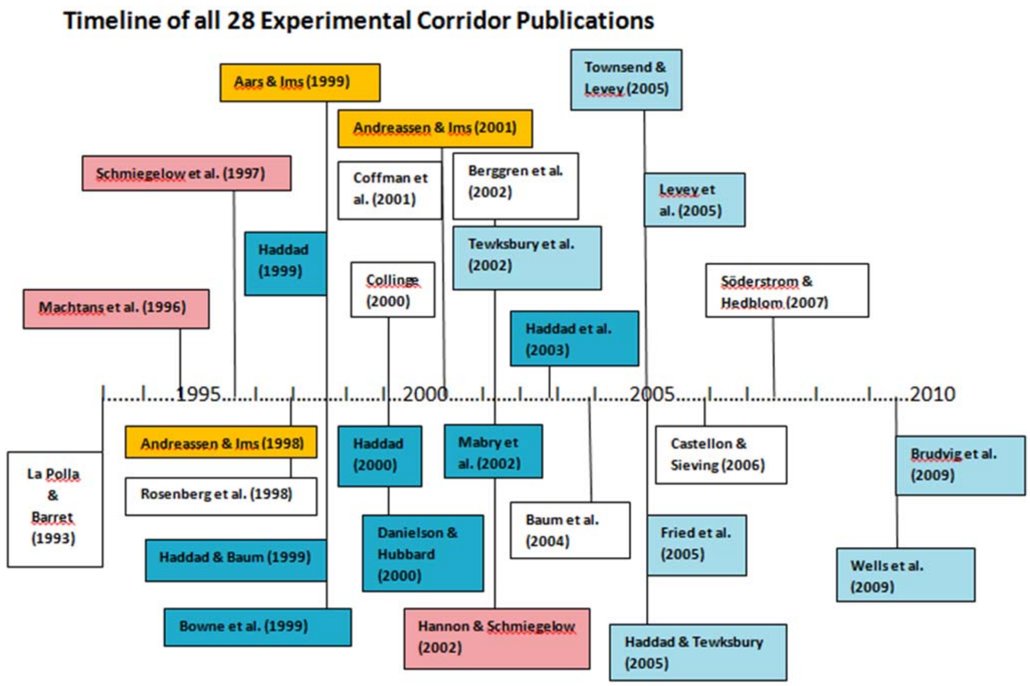

Figure 12.Timeline of all 28 corridor studies. Colors represent continuous studies; plain white represents independent studies, pink for Calling Lake in Alberta Canada, orange for Evenstad Research Station in Norway, and two shades of blue for studies conducted at the Savannah River Site. Dark blue represents the first experimental site and light blue for current experimental site at SRS.

Temporal range for most individual studies averaged 14 months, whereas repetitive studies on established sites averaged 18 months. Of the continuously running studies reviewed, those studies conducted at the SRS site in North Carolina (USA) are the longest running with 18 consecutive years of research. It should be noted that light and dark blue represent two separate experimental landscape configurations (which also includes varying spatial scales) conducted at the same research site. The experiments conducted at Calling Lake in Alberta, Canada placed second in longevity with over 5 years of research followed by the three studies conducted at Evenstad Research Station in Norway with an additional 5+ years.

4.3.4 Results of Taxa Monitored

Organisms studied included plants, insects, small mammals, birds and one amphibian species. More than half of all studies (57%) used trans-located specimens compared to 32% of studies that monitored naturally residing specimens or 10% of studies that used both types. Individual species' studies were more common in the literature than an evaluation of a population.

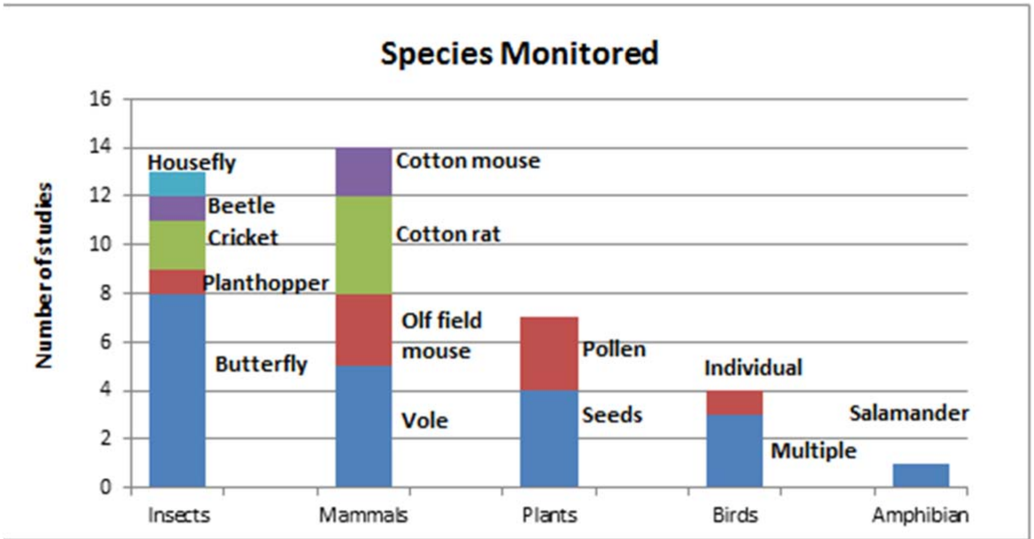

Figure 13 Species monitored

Of the 28 studies reviewed, butterflies were the most commonly studied organism. Of the 8 butterfly species, *Junonia coenia* was the most prevalent amongst the literature. Eight mammal studies were reviewed with voles and cotton rats most commonly monitored. Five studies addressed vegetation dispersal through corridors via host transport. Of these studies, seed dispersal by birds was more prevalently studied than pollen dispersal by insects. A total of 4 bird studies were reviewed with only one study focused on a single bird species, whereas other bird studies assessed multiple species.

4.3.5 Results of Methods Used

Methods used to document species' movement varied, but the most commonly used methods included release and recapture, live trapping, and marking methods. Frequently used marking methods included temporary physical marking of each specimen with a felt-tip pen. Another marking method employed was fluorescent powder tracking, which was used by six studies to identify specimens that were dispersed (such as seed and pollen) and to identify the locations that a specimen had visited.

Multiple methods were utilized in 23 of the 28 studies. Tables 3 and 4 displays the varying methods used by each study. Over half of the studies utilized release and recapture methods as one of the primary design methods for monitoring species. The second most utilized method was the use of live trapping of organisms, followed by vegetation sampling and fluorescent powder tracking. Only 5 studies used a single method for the entirety of the study. Those studies include Hannon & Schmiegelow (2002), Townsend & Levey (2005), Levey et al. (2005), Brudvig et al.(2009) and Haddad & Tewksbury (2005). Tables 3 and 4 present all studies and methods used.

4.3.6 Individual Results

This section will report the individual results of all 28 publications reviewed. More than half (79%) of the studies reviewed (22 of 28) supported the corridor-dispersal hypothesis (i.e. that corridors promote the facilitation of species movement from one location to another) whereas results from 3 studies, (Bowne, Peles et al. 1999; Danielson and Hubbard 2000; Mabry and Barrett 2002) strongly negated the use of wildlife corridors for the specified study organism. Three studies concluded yes-no results, suggesting that corridors did and did not facilitate species movement.
Table 5 displays these results.

4.4 Addressing Objective 3 – *Create a methodology to identify quality scientific evidence of corridor-dispersal function*

All corridor documents were assessed to see how many met the 10 question criteria set out for the third objective. Of the 28 publications only two scored ≥100%; these documents were Haddad (1999) and Collinge (2000). Medium scoring documents (ranging 77%-88%) amounted to 15 documents (54%) and the remainder which scored lower than 66% amounted to 11 studies.
The subsequent sections provide detailed information for each of the Ten Criterion. Tables 6 and 7 display results of the Ten Criteria for all 28 studies.

	Mark, release, recapture (MRR)	*Point count*	*5 Minute count*	*Fluorescent powder*	*Radio telemetry*	*Vegetation survey*	*Netting*	*Pitfall trapping*	*Live trapping*	*Visual observation w/ recorded measurements*	*Individual identification*	*Radioisotope marking*	*Specimen dissection*	*Genetic loci marking*	*Visual observation*	*Tracking tubes*	***Total***
Rosenberg et al. 1998	X							X			X	X					4
Baum et al. 2004	X			X													2
Berggren et al. 2002	X									X							2
Söderström & Hedblom 2007	X					X				X							3
Collinge 2000	X						X			X							3
Hannon & Schmiegelow 2002			X														1
Machtans et al. 1996							X								X		2
Schmiegelow et al. 1997		X				X											2
Castellon & Sieving 2006	X				X												2
Andreassen & Ims 2001	X							X	X								3
Aars & Ims 1999								X	X		X			X			4
Andreassen et al. 1998					X				X								2
Bowne et al. 1999	X				X	X			X								4
Coffman et al. 2001									X		X						2

Table 3 Methods used 1 of 2

	Mark, release, recapture (MRR)	Point count	5 Minute count	Fluorescent powder	Radio telemetry	Vegetation survey	Netting	Pitfall trapping	observation w/ recorded measurements	Individual identification	Radioisotope marking	Specimen dissection	Genetic loci marking	Visual observation	Tracking tubes	**Total**
Danielson & Hubbard 2000	X							X		X						3
Tewskbury et al. 2002	X			X		X								X		4
Haddad et al. 2003	X			X	X	X		X		X						6
Mabry & Bennett 2002					X			X								2
Brudvig et al. 2009				X												1
Townsend & Levey. 2005				X												1
Levey et al. 2005				X												1
Fried et al. 2005	X							X								2
Haddad, N.M. and J.J. Tewksbury. 2005	X															1
Wells et al. 2009								X				X	X			3
Haddad 1999	X					X								X		3
Haddad, N.M. 2000	X													X		2
La polla & Barrett 1993						X		X							X	3
Haddad & Baum 1999			X			X								X		3

Table 4 Methods used 2 of 2

	Citation & Year	Did Corridors Facilitate Species' Movement?
Plants	Levey et al. (2005)	Yes
	Townsend et al. (2005)	Yes
	Brudvig et a.(2009)	Yes
Insects	Haddad (1999)	Yes
	Haddad & Baum (1999)	yes
	Haddad (2000)	Yes
	Collinge (2000)	Yes & No
	Berggren (2002)	Yes
	Baum et al. (2004)	yes
	Haddad & Tewksbury (2005)	Yes
	Fried (2005)	Yes
	Söderström & Hedblom (2007)	Yes, for specialists species
	Wells et al. (2009)	Yes
Amphibian	Rosenberg et al. (1998)	Yes, but so did matrix
Birds	Machtans et al. (1996)	Yes
	Schmiegelow et al. (1997)	Yes
	Hannon & Schmiegelow (2002)	Yes & No
	Castellon & Sieving (2006)	Yes, via wooded corridors and secondary vegetation
Mammals	La Polla & Barrett (1993)	Yes more so than non connected patches
	Andreassen et al. (1998)	yes
	Aars & Ims (1999)	Yes
	Bowne et al. (1999)	No
	Danielson & Hubbard (2000)	No
	Coffman et al. (2001)	Yes
	Andreassen & Ims (2001)	Yes
	Mabry & Barrett (2001)	No
Multi-taxa	Tewskbury et al. (2002)	Yes
	Haddad et al. (2003)	Yes & No

Table 5 Corridors facilitation of movement

	Citation & year	Q.1 Goals	Q.2 Confounding	Q.3 Contro	Q.4 Repetitior	Q.5 Stats	Q. 6 Limits	Q.7 Env.	Q. 8 Target pop	Q. 9 LHT	Q.10 R/I	Score
Plants	Levey et al. (2005)	Y	N	N	Y	Y	Y	Y	N	N	R	6 of 9 = 66%
	Townsend et al. (2005)	Y	N	N	Y	Y	Y	Y	N	Y	R	7 of 9 = 77%
	Brudvig et a.(2009)	N	N	N	Y	Y	N	Y	N	Y	R	5 of 9 = 55%
Insects	Haddad (1999)	Y	Y	N	Y	Y	Y	Y	Y	Y	R	8 of 9 = 88% plus bonus point =100%
	Haddad & Baum (1999)	N	Y	N	Y	Y	Y	Y	N	Y	I	(6 of 9) 66%
	Haddad (2000)	N	N	N	Y	Y	Y	Y	N	Y	R	(6 of 9) 66%
	Collinge (2000)	Y	Y	Y	Y	Y	Y	Y	Y	Y	R	(9 of 9) plus bonus 110%
	Berggren (2002)	Y	Y	N	Y	Y	Y	Y	NA	Y	R	88% (8 of 9)
	Baum et al. (2004)	Y	N	Y	Y	Y	N	Y	NA	Y	R	(7 of 9) 77%
	Haddad & Tewksbury (2005)	Y	N	N	Y	Y	Y	Y	N	Y	R	(7 of 9) 77%
	Fried (2005)	Y	N	N	Y	Y	Y	Y	N	Y	R	(7 of 9) 77%
	Söderström & Hedblom (2007)	Y	Y	Y	N	Y	Y	Y	NA	Y	R	88% (8 of 9)
	Wells et al. (2009)	Y	N	N	Y	Y	N	Y	N	N	R	(5 of 9) 55%
Amphibian	Rosenberg et al. (1998)	y	Y	N	Y	Y	Y	Y	N	Y	R	88% (8 of 9)

Table 6 Ten Criteria score sheet 1 of 2

		Q.1 Goals	Q.2 Confounding	Q.3 Control	Q.4 Repetition	Q.5 Stats	Q. 6 Limits	Q.7 Env.	Q. 8 Target pop	Q. 9 LHT	Q.10 R/I	Score
Birds	Machtans et al. (1996)	Y	Y	Y	Y	Y	Y	Y	Y	N	I	(7 of 9) plus bonus point 88%
	Schmiegelow et al. (1997)	Y	Y	Y	Y	Y	Y	Y	Y	N	I	(7 of 9) plus bonus point 88%
	Hannon & Schmiegelow (2002)	N	Y	Y	Y	Y	Y	Y	Y	N	I	(6 of 9) plus bonus 77%
	Castellon & Sieving (2006)	Y	N	N	Y	Y	Y	Y	NA	Y	R	(7 of 9) 77%
Mammals	La Polla & Barrett (1993)	Y	N	Y	Y	Y	Y	Y	N/A	N	R	(7 of 9) 77%
	Andreassen et al. (1998)	N	N	N	Y	Y	Y	N	N	Y	R	(5 of 9) 55%
	Aars & Ims (1999)	Y	Y	N	Y	Y	Y	N	N	N	R	(6 of 9) 66%
	Bowne et al. (1999)	Y	N	N	Y	Y	Y	Y	NA	Y	R	(7 of 9) 77%
	Danielson & Hubbard (2000)	Y	Y	N	Y	Y	N	Y	Y	Y	R	(7 of9) plus bonus 88%
	Coffman et al. (2001)	Y	N	Y	Y	Y	y	N	y	N	R	(6 of 9) plus bonus 77%
	Andreassen & Ims (2001)	y	N	N	Y	Y	Y	N	N	N	R	(5 of 9) 55%
	Mabry & Barrett (2001)	y	N	N	Y	Y	Y	Y	N	N	R	(6 of 9) 66%
Multi-taxa	Tewskbury et al. (2002)	Y	N	N	Y	Y	Y	Y	N	N	R	(6 of 9) 66%
	Haddad et al. (2003)	Y	N	N	Y	Y	Y	Y	N	N	R	(6 of 9) 66%

Table 7 Ten Criteria score sheet 2 of 2

1. *Published Paper's Aim, Objectives and Overall Goals*

The aim, objective and overall goal are important variables because they guide the study, the investigator and the reader. For this thesis it is important to identify every document's overall focus with relation to corridors and movement. Of all the documents reviewed several topics were discussed and are listed below.

- Movement (inter-patch, distance, rate, behavior and individual species)
- Colonization
- Stepping stones & Matrix
- Fragmentation responses
- Population responses to connectivity in the form of corridors

Eighty-two percent of the publications had goals and objectives directly focused on testing species movement through corridors. Whereas the 5 publications listed below research population parameters. Although these publications focused on the latter they indirectly reported movement dynamics of their study taxa in relation to wildlife corridors.

- Haddad & Baum (1999) whose focus was on butterfly densities;
- Haddad (2000) with butterfly colonization;
- Schmiegelow et al. (1997)'s evaluation of bird resilience to fragmentation;
- Brudvig et al (2009) assessment of plant biodiversity spill over;
- Andreassen et al. (1998)'s study of a population's spatial use responses to patch configuration.

2. *Confounding Variables*

Less than half of the studies reviewed (11 of 28) addressed confounding variables. Table 8 and 9 list the studies that addressed confounding variables as well as those that did not. By addressing confounding variables, researchers and readers are aware of elements that have potential to alter the end results of the study. Researchers may then choose to take steps towards mitigating these elements to continue the initial research originally set out.

Confounding variables associated with design layout	
• Haddad (1999) • Danielson & Hubbard (2000) • Collinge (2000) • Hannon & Schmiegelow (2002) • Haddad & Baum (1999) • Schmiegelow et al. (1997) • Berggren et al. (2002) • Söderström & Hedblom (2007)	• Patch connectedness • Experimental scale • Landscape configuration • Altered survey techniques • Directional influence • Replication

Table 8 Confounding variables associated with design layout

- Both Collinge (2000) and Haddad (1999) discussed confounding effects with consideration to design layout. However Haddad (1999) openly addressed having underestimated confounding variables with regards to the number of adjacent patches that had potential to interfere with the testing of directional and inter-patch movements of the study species.
- For Hannon & Schmiegelow (2002), concerns about confounding effects with connectivity were controlled with a 'Before-After-Control-Impact' design that held patch size constant over time and allowed for altered connectivity.
- Danielson & Hubbard (2000) acknowledged the possible confounding effects of working with large spatial scales. In particular, the authors stressed the significance of the width of the corridors and their preferential role as habitat than as a movement pathway for their study species.
- Schmiegelow et al. (1997) discussed concerns about the undisturbed forest surrounding the experimental site and its potential to "dampen local scale impacts on fragmentation".
- Haddad & Baum (1999) found altered survey techniques to slightly confound their work, limiting the survey comparison between the 2 years.
- Berggren et al. (2002) took precautionary action against the confounding nature of directional influences of the study subject by altering the direction each subject was facing upon release.
- Söderstörm & Hedblom (2007) found that the lack of replication sites confounded their work. To overcome this attribute, they utilized a larger sample size.

Confounding variables associated with study species	
• Rosenberg et al. (1998) • Ars & Ims (1999) • Machtans et al. (1996)	• Identification of species responses • Identification of species related methods

Table 9 Confounding variables associated with study species

- In the case of Rosenberg (1998), confounding effects of naturally occurring salamanders were avoided within the study site by removing them with pitfall traps.
- Aars & Ims (1999) removed individuals that were excessively trapped along the fence perimeter to avoid "fence effect" and abnormal densities.
- Machtans et al.(1996) decided to separate adult and juvenile bird captures, as the differing life stages may affect the individual's reason for moving.

3. *Experimental Controls*

The intent of this question was to identify experimental studies that incorporated reference (control) sites into their experimental design. All 28 studies controlled for some variable. The variables that were most commonly controlled for were landscape configuration (via habitat manipulation), study taxa, environment and spatial scale. Only 8 studies employed reference sites, and those studies are:

- Baum et al.(2004)
- Coffman et al.(2001)
- Collinge (2000)
- Hannon & Schmiegelow (2002)
- La Polla & Barrett (1993)
- Machtans et al.(1996)
- Schmiegelow et al.(1997)
- Söderström & Hedbom (2007)

4. *Replication*

Replication is a valuable tool utilized in experimentation. Without replication, emerging patterns could go unnoticed. Results are also less likely to reflect true representations of the study subject and more likely to include errors or one-off, unrepeatable anomalies. Increasing replication (sites, trials, etc.) within a study creates increased quantities of data, which expands the knowledge base and quality of the study. Of the documents reviewed for replication, all studies but one, Söderström & Hedblom (2007), utilized replication. Tables through list these publications. Tables are arranged by experimental site.

Independent Studies	Replicated Sites
• Baum et al. (2004)	• 20 replicate sites
• Collinge (Collinge 2000)	• 6 replicates of various treatment sizes and connection types
• Coffman et al. (2001)	• 4 replicates of 3 landscape configurations
• Rosenberg et al. (1998)	• 5 replicate sites
• Berggren et al. (2002)	• 12 replicate sites
• Castellon & Sieving (2006)	• 9 replicate sites
• La Polla & Barrett (1993)	• 3 replicates sites

Table 10 Replicated sites for Independent Studies

Calling Lake Experimental Studies	Replicated Sites
• Machtans et al. (1996) • Schmiegelow et al. (1997) • Hannon & Schmiegelow(2002)	• 3 replicates of Isolated patches (1, 10, 40 & 100 ha) • 3 replicates of connected areas (1, 10 & 40 ha)

Table 11 Replicated sites for Calling Lake Experimental Studies

Evenstad Research Station	Replicated Sites
• Aars & Ims (1999) • Andreassen et al.(1998) • Andreassen & Ims (2001)	• 6 replicates sites per year • Total of 12 population replicates

Table 12 Replicated Sites for Evenstad Research Station Studies

Savannah River Site (first experimental site)	Replicated Sites
• Haddad & Baum(1999) - 27 • Haddad (1999) – 27 • Danielson & Hubbard (2000) – 16 • Haddad (2000) - 13 • Bowne et al.(1999) – 10 • Haddad et al. (2003) - 27 • Mabry et al. (2002) – 10	• Experimental area consisted of 27x 1.64 ha plots, with patches measuring 128 x 128m • Not all studies used all 27 plots for experimentation, numbers following authors citation indicates the number of plots used

Table 13 Replicated sites for SRS (first site)

Savannah River Site (recent experimental site)	Replicated Sites
• Haddad & Tewksbury(2005) • Wells et al.(2009) • Fried et al.(2005) • Levey et al.(2005) • Townsend & Levey(2005) • Brudvig et al.(2009) • Tewksbury et al.(2002)	• 8 x 50 ha plots • Each block contains one source patch (100 x 100m) connected by corridor to one target patch of equal area • One rectangular receiver patch (100 x 137m) • 2 x winged patches with equal area to rectangular patch but with different configuration

Table 14 Replicated sites for SRS (recent experimental site)

Only one study did not utilize replicate sites (Söderström and Hedblom 2007). Due to spatial limitations, Söderström & Hedblom, (2007) used one replicate of each experimental strip to perform their butterfly study. Researchers compensated for lack of replication sites by using a large sample size of 425 butterflies.

5. Statistics

Within the scientific field the use of statistical analysis (the collection, organization, and interpretation of data) is frequently used and is seen as a requirement by the scientific community for producing reliable scientific results. All studies reviewed successfully incorporated some type of statistical analysis to solidify their experiment.

6. Limitations

More than half of the studies, 86% stated limitations pertaining to their studies. Spatial and temporal scale along with uncontrollable weather conditions were the most common limitations and survey inconsistencies represented the most acknowledged common errors found in all documents reviewed. The four studies that did not state any limitations include Danielson & Hubbard et al.(2000), Baum et al.(2004) , Brudvig et al.(2009) , and Wells et al.(Wells, Williams et al. 2009)

7. ***Environmental Conditions***

There are still many unknown variables linked to ecosystem functions that as a consequence of alterations (habitat manipulation) may result in new and unknown ecological changes. Collecting information on environmental conditions prior to an expansive habitat manipulation can assist with the investigation and understanding of future potential interactions. Environmental conditions were addressed by 86% of the studies reviewed. The 4 studies that did not include details of any assessment prior to habitat manipulation were Andreassen et al. (1998), Andreassen & Ims (2001), Aars & Ims (1999) and Coffman et al. (2001).

8. ***Target Population Parameters***

Findings show that only 25% of the studies conducted target population parameter assessments before and after habitat manipulation. These studies were allocated one bonus point to their total score. More than half (54%) of all publications reviewed did not conduct any such assessments and 21% of studies were non-applicable; in that they used translocated species. Target population parameters are critical as they give researchers a general understanding of variables that may be contributing to the circumstances and constraints of a specific species population. Listed below are the studies that conducted target populations' parameter assessments.

- Coffman et al. (2001)
- Collinge (2000)
- Danielson & Hubbard (2000)
- Haddad (1999)
- Hannon & Schmiegelow (2002)
- Machtans et al. (1996)
- Schmiegelow et al. (1997)

9. Life History Traits

Life history traits give information about species-specific characteristics such as breeding and feeding requirements and behaviours, species-specific desired habitats, and anatomical functions and features. These characteristics may be important for identifying species-specific variables needed for the design of appropriate study methods.

Over half (57%) of the studies discussed life history traits of the specified study taxa. Those studies that did not address life history traits mainly included studies that experimented with single species. Tables 15 and 16 display the studies (which are categorized by study taxa) that did and did not address life history traits.

Studies that did not address life history traits	
Multiple taxon studies; • Machtans et al. (1996) • Hannon & Schmeigelow (2002) • Schmeigelow et al. (1997) • Haddad et al. (2003) • Tewksbury et al. (2002)	Single taxon studies; • Mabry & Barrett (2002) • Levey et al. (2005) • Wells et al. (2009) • Andreassen & Ims (2001) • Aars & Ims (1999) • Coffman et al. (2001) • La Polla & Barrett (1993)

Table 15 Studies that did not list LHTs

Although the life history traits of the particular organism being studied may not necessarily play a critical role in the design of the experiment, it is important for the author to convey to the audience that such potential variables had been considered.

Studies that did address life history traits	
Multiple taxon studies; • Collinge (2000) • Haddad & Baum (1999) • Söderström & Hedblom (2007) • Haddad (1999) • Townsend & Levey (2005) • Danielson & Hubbard (2000)	Single taxon studies; • Rosenberg et al. (1998) • Castellon & Sieving (2006) • Baum et al. (2004) • Haddad (2000) • Berggren et al. (2002) • Haddad & Tewksbury (2005) • Fried et al. (2005) • Bowne et al. (1999) • Andreassen et al. (1998) • Brudvig et al. (2009)

Table 16 Studies that addressed LHTs

10. Species Movement; Recorded or Inferred?

Of the 28 publications reviewed, four studies inferred species movement through the evaluation of population parameters such as species abundance, species richness and density.

- Haddad & Baum (1999)
- Hannon & Schmiegelow (2002)
- Machtans et al. (1996)
- Schmiegelow et al.(1997)

The remaining 23 studies were regarded as recorded studies as they tracked the organism's movement throughout the experimental landscape and matrix.

4.4.1 Results for Objective 3

After evaluating all of the documents against the ten criteria, only two documents, Haddad (1999) and Collinge (2000) met all of the listed criteria, scoring the highest (100% or greater) and providing sufficient evidence to support and/or contradict the utilization of corridors as movement conduits for organisms.

Both studies were similar in their conclusions, that corridors did facilitate species movement. Collinge (2000) found that corridors assisted the movement of only one of her study insects "the Darkling beetle concentrated their movement activity in corridors, whereas Crickets and June beetle movements were not confined to corridors"(Collinge 2000). Haddad (1999) also studied insects, particularly *Junonia coenia* and *Euptoieta claudia*. This study observed and recorded both butterfly movements between patches connected by a corridor. Figures and include brief abstracts of their work.

Collinge's (2000) paper, *Effects of Grassland Fragmentation on Insect Species Loss, Colonization and Movement patterns*, published in the journal of Ecology closely assessed the movement behaviour and patterns of three different insect populations (June beetle, Darkling beetle & cricket) in response to habitat fragmentation of a grassland ecosystem in Colorado, USA. Although she established many hypotheses regarding the recolonization of patches, the one hypothesis that this review was most focused on was if insects would prefer corridors as movement pathways to matrix environment.

The design layout involved 3 connectivity treatments (isolated, connected and control) consisting of different sized patches (small $1m^2$, medium $10m^2$ and large $100m^2$) arranged in a reflected duplication of 6 blocks. This design set up allowed for a total of 54 replication plots. It is important to note that connectivity treatments were left intact (uncut), whereas surrounding matrix was altered (cut).

Collinge (2000) established a thorough methodological protocol where environmental conditions, population parameters and life history traits of the study subjects were assessed prior to habitat manipulation. Monitoring insect movement consisted of mark-release-recapture of an insect (on an individual basis) with movements observed by the researcher. Distance of each movement was recorded using marking steaks to measure the total distances that the insects moved.

Collinge (2000) concluded that "corridors functioned to increase movement among habitat patches for some insect species and had a slight positive effect for less mobile insect species".

Figure 14 Collinge (2000) Summary

Collinge (2000) applied robust methodological protocol which has resulted in a study of sound scientific results. Replication and similar results by additional researchers could support the findings made by Collinge (2000).

Haddad's, (1999) *Corridors and distance effects on inter-patch movements: a landscape experiment with butterflies*, published in the journal of *Ecological Applications* discusses the trials of evaluating butterfly dispersal in large connected and unconnected experimental landscapes. The experimental site consisted of 27 equally sized (1.64-ha) replicate patches of early successional growth both connected (via corridors of varying distances 64-384m) and unconnected to nearby patches. Experimental patches and corridors were surrounded by a matrix of thick pine forest that yielded no understory.

The movements of two native butterfly species *Junonia coenia* and *Euptoieta claudia* were monitored using a mark-release-recapture method as well as direct visual observation. Haddad (1999) implemented necessary methodological protocols to avoid confounding effects by conducting a vegetation assessment, collecting target population parameters and considering life history traits of study subjects prior to experimentation.

Results from Haddad (1999) concluded that both butterfly species moved more frequently through connected patches then through dense pine matrix to isolated patches. Movement rates between connected patches were increased for both species in the two years the study was conducted. For *Junonia coenia* inter-patch movement was significantly positively dependent on the abundance of the host plant *Linaria canadensis.* Results also indicated that male *Junonia coenia* were significantly positively dependent on corridor presence. Similarly, *Euptoieta claudia* was also significantly positively dependent on the presence of corridors.

There was no significant difference in the comparison of the shortest distance (64m) between connected and unconnected patches. At larger patch distances (>64m) both species of butterfly displayed a preference to use corridors to gain access to connected patches compared to crossing through the matrix to isolated patches.

Figure 15 Haddad (2000) Summary

Human error may always potentially affect the results of visual observation. There is a need for investigators to strive to minimize such errors. Standardization of methods assists with decreasing some of these issues by openly addressing potentially confounding variables. Haddad (1999) sufficiently took such precautionary measures by directly addressing confounding variables, conducting target population assessments pre- and post- habitat manipulation as well as conducted a vegetation survey. Haddad (1999) provides evidence to support the utilization of corridors on a large spatial scale by two butterfly species.

4.5 Conclusion

From this literature review it was ascertained that the majority of the experimental corridor studies were large scale experiments conducted within forested environments in the Northern Hemisphere. The temporal range of one-off studies averaged at 14 months whereas repetitive corridor studies on an established site averaged 18 months. Study taxa included plants, insects, small mammals, birds and one amphibian species. A greater number of the documents used trans-located specimens compared to resident specimens and conducted individual based research more so than population scale research. Of the methods used to monitor study taxa, release & recapture, live trapping and marking methods were amongst the most frequently used. Upon comparison of each paper's individual results, the corridor hypothesis was supported by more than half of the studies reviewed, therefore supporting my first hypothesis. My second hypothesis (that less than half of the experimental corridor publications reviewed will successfully score ≥100% in my methodology, presenting little quality scientific evidence of corridor-dispersal function) was correct as only two documents met the 10 question criteria Haddad (1999) and Collinge (2000). Both publications presented high quality evidence to support corridors as a movement conduit for their study taxa.

5 Wildlife Corridors and Nature Conservation

5.1 Introduction

In this chapter I will briefly discuss the historical perspectives of corridors over the last 30 years and the number of directions the subject has expanded to. This will help to give readers an understanding of the progression and evolution of corridor ecology. Then I will explore the use and value of corridors in the 21st century. I will conclude with a focus on how experimental corridors contribute towards nature conservation with examples of their applications.

5.2 An Historical Perspective

Wildlife corridor research 'blossomed' in the late 1980's and 1990's. This may have resulted from a growing awareness of habitat fragmentation, declining habitat and the extinction of many species. With a worldwide focus on environmental issues, nature conservation efforts were considered to be of great importance. Emphasis was directed towards the protection of national parks and reserve design as well as overcoming habitat fragmentation with corridors and wildlife crossings over and under roadways. In 1978 several large scale wildlife corridors (overpasses and underpasses) were constructed in Banff National Park in Canada to mitigate the negative effects of the Trans Canadian Highway. Following the implementation of these wildlife corridors, numerous design-related corridor studies resulted with a focus on corridor efficacy.

By the early 1990's ecologists realized there was a lack of scientific evidence available which supported the use of corridors. This demand for stronger scientific evidence of biotic movement and the growing environmental movement resulted in advancements in dispersal related science. This in turn led to the development of new and innovative study methods for monitoring species' dispersal.

Experimental landscape studies directly exercised elements of control to evaluate behavioural responses to different landscape configurations. The first experimentation on corridors began with La Polla & Barrett's (1993) vole fragmentation experiment. La Polla & Barrett (1993) monitored vole dispersal through a small scale fragmented landscape that employed two landscape types, connected (via corridors) and unconnected. As seen from the results in chapter 4, this simple experimental methodology was developed towards the end of the 20th century and has sustained into the 21st century.

The late 1990's marked the innovative use of genetic identification with its ability to track animal movements from one location to another. By analysing microsatellite loci, population geneticists can identify kinship between animals within populations or communities. This information along with recorded landscape features and behavioural traits can assist with the identification of movement pathways of specified animals.

5.3 Are Corridors Still Relevant in the 21st Century?

With such a concentration of corridor studies ranging from the 1980's through to the 1990's and then subtly decreasing in quantity over time, I felt it necessary to create a section that reviewed relevance and utility of corridors in the 21st century. I extended my research to briefly appraise and discuss the progression of corridor use and how corridors are socially valued as a conservation tool currently in 2012. This section is a collection of recent information on corridors collected from online sources and through direct correspondence with conservationists working with specific corridor projects.

5.3.1 Design Oriented Corridors in the 21st Century

With the expansion of and excessive use of highways in the United States, animal-vehicle collisions are of a serious concern for both humans and wildlife. Efforts to minimize occurrences with the use of wildlife crossing signage has assisted with informing drivers about the apparent underlying risks but does nothing to abate wildlife from crossing busy transport lines. To keep wildlife off highways, fences have been installed parallel to roadways. This option offers maximum safety to both wildlife and drivers but unfortunately interferes with migration routes and species dispersion. As seen in Baniff National Park, an effort to 'bring back' the wildlife overpass is taking place in Colorado with the Animal Road Crossing (ARC) 2011 - International Wildlife Crossing Design Competition. ARC organization is comprised of several foundations, NGOs (non-governmental organisations), transportation agencies and universities in Canada and in the U.S., which formed this competition to address the interface problems between wildlife and drivers along Colorado's highway I-70. Corridor designs were submitted by various contestants from all over the world. The winning designers were HNTB with Michael Van Valkenburgh & Associates; whose design met the functional, ecological and aesthetic qualities that ARC were in search for. For more information see the ARC competition website http://www.arc-competition.com/welcome.php.

Figure 16 HNTB MVVA Team, hypar-nature, winning wildlife road crossing design, which will allow wildlife to cross over the busy highway through a wooded corridor.

5.3.2 Genetic Related Corridor in the 21st Century

Two examples of genetic related corridor studies include Perez et al. (2010) and Dixon et al. (2006) Both studies focus on bear populations and their genetic relevance with regards to dispersal through corridors. Research by Perez et al. (2010) genetically links two isolated Cantabrian brown bear subpopulations and identifies the dispersal path which facilitate males' migration through the Cantabrian Mountains of Spain.

Research by Dixon et al. (2006) also links two bear populations and identifies a corridor (known as O2O which is part of Florida's Ecological Greenway Network) that males utilize as a dispersal pathway between reserves. This corridor connects two national forests, Ocala and Osceola, which are centrally located in north Florida. Current conservation initiatives taking place include monitoring bear locations using GPS collars on acquired land near Camp Blanding in Starke, FL . Conservationists are hoping to acquire this land for the O2O (McCown 2012).

Figure 17 Advertisement of Florida's Wildlife Corridor, also known as Florida Ecological Greenway Network. Photo obtained from Florida Wildlife Corridor Expedition website https://www.facebook.com/FloridaWildlifeCorridor/timeline#!/FloridaWildlifeCorrido

5.3.3 Observational Corridor Research in the 21st Century

In many developing countries such as Tanzania, Kenya and Uganda, observational methods are the only methods available for scientific documentation as many resources (financial & technological) are very limited or not available. Researchers in Tanzania are working hard to minimize the changing landscapes of the Selous- Niassa wildlife corridor. This is a vital distribution path for many large mammals such as elephants. Hofer et al. (2004) and Ntongani et al. (2009) both report how the changing landscape and the interface between humans and wildlife in the Selous- Niassa poses a threat to wildlife conservation in Southern Tanzania.

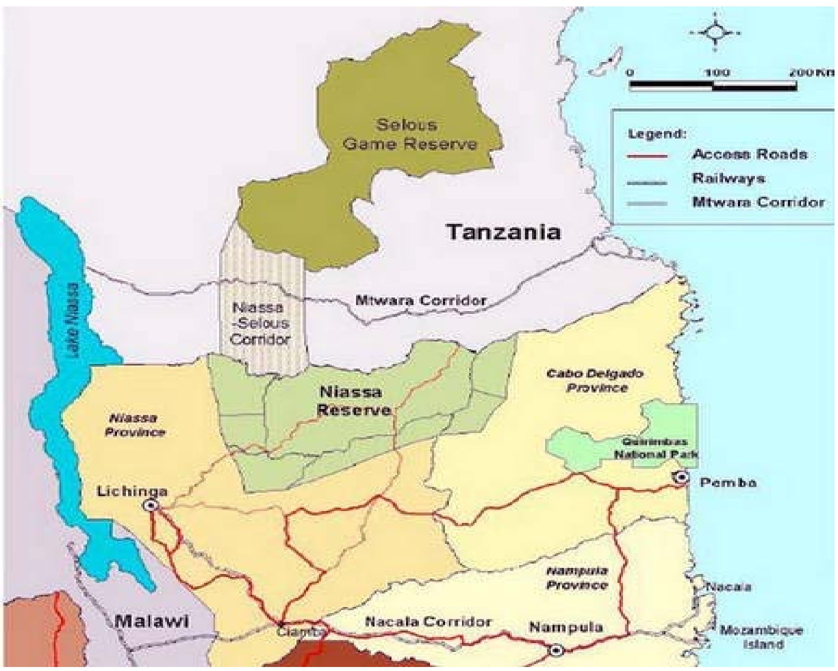

Figure 18 Selous-Niassa Corridor. Picture retrieved from Niassa Carnivore Project website http://www.predatorconservation.com/niassa.htm

5.4 How does Experimental Corridor Research Contribute to Nature Conservation?

Experimental corridor research is a practical means towards reducing the negative effects of fragmentation (that could lead to extinctions of populations) by increasing species' diversity with the restoration of wildlife habitat and by the promotion of genetic flow through the installation of connections between otherwise isolated patches. Experimentation allows researchers to better understand the dynamics of the metapopulation theory as well as collect data on movement behaviours of various subjects under various conditions. These data are vital to theoretical ecology as well as potentially developing applications towards new advancements in technology. These advancements (mentioned below) add to the knowledge base and evolution of corridor ecology that can be applied towards land management, restoration and stewardship efforts.

5.4.1 Advancement of Methods and Technologies

One by product of experimental corridor research is the advancement of technologies. It is common practice for the development of new and innovative study methods to originate from changing investigation objectives. Below are two examples of new seed tracking methods that resulted from experimental corridor research.

5.4.1.a Fluorescent Powder Tracking

Levey & Sargent (2000) were successfully able to track bird dispersed seeds by applying fluorescent microspheres to fleshy fruits and then locating seeds from faecal samples. This procedure was utilized by several other researchers (Tewksbury, Levey et al. 2002; Haddad, Bowne et al. 2003; Levey, Bolker et al. 2005; Townsend and Levey 2005; Brudvig, Damschen et al. 2009) who also conducting studies at the Savannah River Site in North Carolina (U.S.A.).

With the success of fluorescent powder tracking I found it unusual that this method had not been utilized more frequently among researchers. After searching the scientific database *Web of Knowledge* I was able to locate only one other publication that used fluorescent powder for tracking seed dispersion by bats in the Philippian islands (Reiter 2006).

Dr. Levey (personal communication) informed me of the disadvantages of fluorescent powder tracking. First, the process of locating and identifying faecal samples as well as sorting through faecal samples was very time consuming and difficult. Secondly, the fluorescence was degraded by the exposure to UV light and lastly there may be unknown animal health effects associated with the consumption of fluorescent powder (Levey 2012).

5.4.1.b $_{15}$N Isotope Enrichment Seed Tracking

In response to the disadvantages of fluorescent powder tracking and methodological shortcomings in tracking the dispersal of seeds, Carlo et al. (2009) developed the $_{15}$N isotope enrichment seed tracking method.

During the flowering stage, researchers sprayed plants with $_{15}$N –urea so that developing seeds would be isotopically enriched with $_{15}$N. In a trial experiment seeds and seedlings were found to be of a “linear function” of the $_{15}$N urea (Carlo 2009). In a field experiment plants were sprayed a total of three times. Seeds presented long lasting enrichment levels even after germination, holding levels up to masses by at least two orders of magnitude before fading (Carlo 2009). At this point it is unknown if this technique has been tested with any dispersing host.

5.4.1.c Ecological Computer Modelling Software

A computational model is a program that has been designed to statistically model input data to find analytical solutions and attempt to simulate predictions of the behaviour of a system from a set of parameters and initial conditions (Jorgensen 2001). Although computer modelling is not reality and has to some degree limitations, it has many advantages. Some of these include the ability to provide information about future behaviours, risks and effects of a system by the adjustment of different variables or events. An example of this would be how a natural disturbance such as fire could affect the distribution capabilities of mobile flying insects (Haddad 2006).

Another advantage of modelling is its ability to bypass construction or establishment of experimental projects, that may have unknown structural flaws or be costly and time consuming. One example is Levey et al. (2008) in which modelling was utilized for long-distance seed dispersal in a heterogeneous landscape. Prior to this project, Levey et al. (2008) stated that:

> “the model was parameterized with small-scale movement data collected from field observations of birds. In a previous study we validated the model by testing its predictions against observed patterns of seed dispersal in real landscapes with the same types and spatial configuration of patches as in the model.”

Although the researchers did conduct the initial necessary field work, they are now able to proceed and test various hypothetical questions (with limitation) without conducting any further field research.

Lastly Rosenberg et al. (1998) addressed the idea that model systems offer opportunities to test for patterns at spatial scales that would be extremely difficult to test for in the field. One example, testing seed dispersal at long distances through heterogeneous landscapes, is a relatively difficult task with methodological short comings at such large spatial scales (Levey 2008). Hence many large landscape-scaled experiments require the assistance of computer modelling.

5.4.2 Increased Species Diversity

In several cases (studies that were conducted at Savannah Research Site - SRS) it was documented that the creation of corridors leads to the increase in plant species richness (Damschen 2006). Unlike most other corridor experiments reviewed for this thesis, the landscape configuration used to create patches and corridors at SRS was the inverse of the conventional "corridor style", in that patches and corridor were secondary growth of various types of vegetation, rather than a homogenious habitat. Researchers at the SRS established their experiments within a homogeneous pine forest, where designated patches and corridors were cut and burned away, allowing for open areas where successionary processes occurred. By allowing succession to take place, viable seeds of the soil seed bank compete for recently available resources (sunlight, water & nutrients).

The initial species to succeed in populating a disturbed area are generally more likely to be r-selected species. R-selected species are characterized by their allocation of energy towards producing multiple offspring (quantity over quality). R-selected species are generally classified as being smaller in size, having a short life expectancy and dying within a short period of time. Many "weeds" are considered to be r-selected species. The opposite to r-selected species is K-selected species. These are generally larger organisms that produce fewer offspring, mature later and have a longer life expectancy (quality over quantity). Examples of K-selected species are slow-growing trees that will eventually out-compete r-selected species by gradually shading out competitors with a canopy, thus "relaxing" an ecosystem.

Increased species diversity can also be attributed to remnant corridors (corridors not originating from succession, but vegetation left intact after a landscape manipulation). Most literature written in respect of corridors and their management emphasize the importance of a heterogenous mixture of vegetation to support and cater to a larger variety of species. Homogenous landscapes (such as pine plantations) generally have lower levels of species' diversity largely due to land management practices.

5.4.3 Diversification of Corridor Ecology Research

Over the last 3 decades huge efforts appear to have been made to remedy fragmentation with the use of corridors. Through the dichotomy of practices (observational, experimental, transportation-design oriented and genetics), corridor ecology has flourished. The implications of extensive research in these fields have developed new sub-disciplines of ecology that not only apply to corridor ecology but also apply elsewhere. Below is a list of sub-disciplines that have been influenced by corridor ecology and have also influenced the development of corridor ecology.

- Applied ecology
- Biogeography
- Conservation ecology
- Disturbance ecology
- Evolutionary ecology
- Invasion ecology
- Landscape ecology
- Restoration ecology
- Successional ecology
- Urban ecology

The multiplication of such sub-disciplines has potential to contribute towards nature conservation by allowing researchers to focus efforts on specialized issues. However, this may also be problematic as ecosystems (and their related issues) are holistic and require holistic solutions. To be most efficient and effective in contributing to conservation efforts, specialized researchers will need to network (allowing for the blending of sub-disciplines) to achieve a united goal. These networking goals could be met with annual conferences, specialized research centers or publications dedicated to addressing the linkage between sub-disciplines. In the next section, several of these sub-disciplines (conservation ecology, invasion ecology, restoration ecology and disturbance ecology) are discussed as they directly relate to the application of experimental corridor research towards nature conservation.

5.5 Current Application of Experimental Corridor Research

Many of the technologies mentioned above have been applied outside the scientific realm for the benefit of nature conservation. I shall discuss how these technologies are being implemented by land managers for restoration and stewardship efforts.

5.5.1 Land Management, Restoration & Stewardship Efforts

Land management is the maintenance, use and development of land resources (including but not limited to soil, minerals, timber, water and animal inhabitants). Management practices differ depending on what the land can offer to human society, what is being utilized from the land and what landowners have planned. For public lands that have been set aside for conservation purposes, a balanced management strategy may be required to meet both wildlife and societal needs. Land managers may be responsible for maintaining a functioning ecosystem that will not impose any threat to the quantity or quality of resident species, while at the same time provide the public with suitable land for recreational activities (hiking, biking, hunting etc.). Such a task requires long and short term goals, with set plans and procedures. Restoration initiatives such as invasive species' removal and habitat development are frequently employed to achieve set conservation goals. Forethought for the delicate inter-workings of every ecosystem is required when initiating a large scale restoration project. This is where technological advancements from corridor experiments may be applied. Discussed below are examples of three applied technological advancements.

5.5.1.a Fluorescent Powder Seed Tracking

Two separate programs have utilized the fluorescent powder seed tracking method. The first application (Reiter 2006) was used to monitor seed dispersal by bats in rain forest environments of the Philippian islands by researchers from Ruhr University Bochum in Germany. Fluorescent pigment was mixed with acetone and applied to fruit (*Ficus septica & Ficus variegate*) to study seed dispersal by bats. Fruit was eaten, digested, defecated and re-located, resulting in random seed dispersal. Researchers concluded that fluorescent powder tracking was a simple, inexpensive and non-invasive method allowing seed dispersal and establishment to be examined quantitatively

(Reiter 2006). The authors state that “the technique provides a critical tool for linking the study of seed dispersal to plant population biology” (Harper 1977; Howe 1982; Herrera 1994; Reiter 2006).

The second application of this method was by the Colorado Division of Wildlife to gain knowledge of the seed dispersal capabilities of an invasive plant species, *Bromus tectorum L.*, commonly known as cheatgrass. In Johnston (2009) researchers allowed 1,300 sterilized and marked seeds to be wind dispersed from three environment types (mesa top, gully and ridge top). Seeds were located by blacklight at night. Distance from end point to origin and distance to nearest neighbour were recorded. This research concluded that the absence of impediments promoted further seed dispersal and found that 5% of cheatgrass seeds travelled further than 10.6m over bare soil (Johnston 2009). Research on cheatgrass seed dispersal was in coordination with the restoration of conservation lands in Colorado (U.S.A.). Information gained from this experiment will assist scientists and land managers in planning the most appropriate and efficient method for cheatgrass removal and subsequent ecological restoration.

5.5.1.b $_{15}$N Isotope Enrichment Seed Tracking

One application of $_{15}$N isotope enrichment seed tracking experimentation was recently conducted in the natural landscape of Patagonia, Argentina. In the document *Neighbourhood effects on seed dispersal by frugivores: testing theory with a mistletoe-marsupial in Patagonia*, by Morales et al. (2012), researchers tested theoretical predictions of effects of neighbouring species on density and patch size of conspecific mistletoe, rate of seed removal and seed dispersal distances of mistletoe by marsupials in north western Patagonia, Argentina. Using $_{15}$N isotope enrichment technique, researchers identified and tested 20 mistletoe samples within a 15.5 ha plot with specified distances between each sample to represent a gradient of low to high intraspecific neighbourhood densities (Morales 2012).

Results of the study indicated that denser groupings or neighbourhoods of mistletoe had greater fruit removal rates and displayed shorter mean dispersal distances. More remote, isolated, mistletoe patches (less dense), had a lower fruit removal rate but displayed a longer seed dispersal distance. Conservation implications of this new technology has yet to be applied outside the scientific realm but has potential to be used in coordination with modelling software to assess plants' invasion dynamics, evaluate plant population responses to climate change and assist land managers with the restoration of endangered plant species (Morales 2012).

5.5.1.c Computer Modelling Software

Computer modelling, specifically connectivity software, is currently being applied by land managers of the Sandhill Area Land Trust, the North Carolina Sandhills Conservation Partnership and other federal bodies in North Carolina (U.S.A.) for the conservation of the endangered St. Francis Satyr butterfly. *Neonympha mitchellii francisci* is a highly endangered sedentary butterfly restricted to several small subpopulations in the shallow wetland and glade habitats of the natural lands owned by Fort Bragg, North Carolina. Under the Federal Endangered Species Act of 1973, conservation initiatives are to be applied to lands which endangered resident populations depend on. These initiatives range from acquisition of land and grant-in-aid to active and adequate conservation programs of threatened or endangered species or ecosystems (ESA 5 & 6 USC 1973).

In 2000 the North Carolina Sandhills Conservation Partnership (NCSCP) was formed by federal, state and non-profit conservation groups for the conservation and long-term sustainability of long-leaf-pine habitats and endangered wildlife populations. With the financial assistance of the Strategic Environmental Research & Development Program (SERDP) researchers from University of North Carolina (UNC) were given the opportunity to create connectivity computer modelling software capable of identifying dispersal corridors through fragmented landscapes. This connectivity model is currently being applied to the conservation of endangered wildlife such as the St. Francis Satyr butterfly and for stewardship efforts of the Sandhill area (Breckheimer 2012).

The St. Francis Satyr butterfly was discovered in 1983 and thought to have gone extinct relatively soon afterwards. The butterfly was rediscovered in the mid 1990's in a small area within the Sandhill's landscape of Fort Bragg, North Carolina. Over twenty years of research have been conducted to gather vital information for the protection of this species. Kuefler et al. (2008) specifically reports on the distribution range, habitat association, population size and trends, demographic parameters and the spatial aspects of the species' population's structure as well as laboratory rearing of butterflies.

Other studies (Hudgens 2002; Haddad and Tewksbury 2005; Haddad 2008; Bartel 2010; Hudgens N.D.) have utilized modelling software to assist with the spatial distribution and connectivity of these butterflies throughout the landscape and between subpopulations. Researchers have concluded that this species relies heavily on disturbances such as fire, flooding and beaver's to achieve and maintain an open successionally active ecosystem. Appropriate land management techniques to sustainably maintain these important ecosystems are being initiated by conservationists and land managers to increase the population of this endangered species. Researchers and conservationists anticipate increased numbers within subpopulations, upon which the St. Francis Satyr butterfly will be reclassified as threatened instead of endangered.

Experimental corridor research has contributed towards nature conservation in many ways. Through the advancement of technology, researchers, land managers and conservation planners can monitor species movement as well as identify specific population parameters of endangered species, species inhabiting sensitive ecosystems or species that are difficult to study. Such information can directly assist with the restoration and stewardship efforts to increase habitat diversity and connectivity between fragmented landscapes. With every experiment conducted comes knowledge to further the discipline of corridor ecology. Over the last three decades corridor research has expanded and diversified. Current corridor initiatives are applied worldwide in a united attempt to mitigate the negative effects of fragmentation by reconnecting populations. I believe this trend will continue as long as conservation initiatives continue to be supported by governing bodies, academic institutions, conservation organizations and the involved public.

6 Discussion

6.1 Discussion Topics Chapters 1 – 3

6.1.1 Thesis Time Frame

As mentioned prior, this Masters thesis originally began as a broad review of wildlife corridor studies of all animals (with the exception of invertebrate and aquatic species), across all locations and including all terrestrial landscapes. Limitations were then set, particularly a time frame was established from 1995 to 2010. Upon designing the methodology for objective 3, I found myself struggling to create one methodology that could be used to assess all publications across all categories. I also realized quickly, that with such a large amount of publications I would not be able to conduct a thorough enough evaluation as I had so desired. Weighing my options, I decided to focus on corridor experiments. From there the methodological design took shape, but the time frame was still left at 15 years. The thesis time frame did not change until after this thesis was completed. Upon review, I felt that this examination of corridor experiments was incomplete due to the restrictions of the time frame and the exclusion of La Polla & Barrett (1993). Thus, a revision to include the publication, alter results and extend the time frame occurred. During the course of this final revision, new information surfaced indicating that La Polla & Barrett (1993) was not the first corridor experiment but in fact Lorenz & Barrett's (Lorenz 1990) *Influence of simulated landscape corridors on house mouse (Mus musculus) dispersal.*

6.1.2 The Ten Criteria

Developing a methodology to evaluate the quality of science produced by experimentation is by no means an easy task. As mentioned in chapter 2, the ten criteria was created with variables that I felt were necessary and important for this explicit task and therefore this methodology is not suited for any purpose, other than assessing corridor-dispersal function of experimental corridor publications. With any new methodology or scientific design, criticism will precede to test the credibility and reliability of the method. This may also stimulate further critique or alteration of the design. The ten criteria was not created as a weighted system (in which some variables carry more relevance than another, therefore holding more weight) but more as a method to identify important variables related to corridor experimentation. This is not to say that this methodology is correct or incorrect, but stands as a "stepping stone" publication for future corridor qualitative evaluations.

6.2 Discussion Topics Chapter 4

6.2.1 Spatial Scale – Influencing Species Movement

One important observation made from this review was that source patch area had potential to influence species movement. Having too small or too large of an area can result in a mobile or stationary response. Upon the introduction of a study species to its source patch the subject must decide whether to stay or leave the area. This decision may be based on several factors including precautionary behaviours, available resources, and area.

One example; Baum et al. (2004) recorded plant hopper movement from a source patch of 0.58m², over a distance of 2m (via corridor or by stepping stones) to the nearest patch. The total experimental area of each replicate was 39.4m². By releasing the study subject in a spatially restrictive area (that could not be used as habitat) it may have induced the movement of the study subject. This could have been researchers intent to induce movement, in which case this should have been stated. The movement capabilities of the study taxa were also not addressed. Researchers did not include plant hopper home range area or total travel distance. This information would have been helpful in interpreting the movement behaviours of this insect.

In contrast, Tewksbury's et al. (2002) study was conducted at the Savannah River Site in North Caroline (USA) with a total experimental area of 50 hectares. Their study monitored the movement of butterflies from source patches measuring 1 hectare in size, over a distance of 150m (through connected and unconnected area) to the nearest patch. Tewksbury et al (2002) provided information of specific butterfly home range area and furthest travel distance in the publication. Providing this information adds to the knowledge base, assisting with conservation and protective efforts.

6.2.2 Calling Lake Experiments

Despite the moderate score these three studies (Machtans, Villard et al. 1996; Schmiegelow, Machtans et al. 1997; Hannon and Schmiegelow 2002) were given, I need to acknowledge the invaluable information these publications have contributed to the scientific community. The Calling Lake experiments were conducted at an extensively large scale (14,000 ha). Machtans et al. (1996) was well organized and initiated pre-habitat manipulation assessments prior to the occurrence of deforestation. From my research, Machtans et al. (1996) was the earliest experimental corridor study to employ such an innovative and holistic design. For this reason, I included it into the Ten Criteria.

The research conducted at Calling Lake gives ecologists, conservationists, land managers, and industry planners a picture of the environmental dynamics associated with mass clear cutting of mixed boreal forest. In particular this picture describes population parameters and behaviours of birds pre-and-post deforestation. Which potentially has influenced the future of both the forestry industry and conservation initiatives.

On the basis of providing quality science for corridor-dispersal functionality, it was scored as moderate. The study was ambitious with regards to its scale and its focus on multiple bird species. Obtaining accurate and precise bird movements is a difficult task. Unless financial resources are available for more reliable tracking methods, the study can only provide inferential conclusion, which I personally feel does not provide strong enough evidence to be regarded as an high quality experimental corridor study.

6.2.3 Savannah River Site – SRS

Fourteen corridor studies reviewed in this thesis were conducted at SRS in North Carolina, USA. Similar to the Calling Lake studies, SRS is also a landscape sized experiment, with the original site conducted in 110ha and the newer site utilizing 50ha. Researchers have teamed up with the US forestry service to achieve their landscape design. In return the US forestry service profits off the lumber production, and both bodies are working together to restore the area to its natural state, with native vegetation, as part of a restoration initiative. Unlike the Calling Lake experiments, researchers from SRS specifically designed their experiments to test corridor-dispersal function and over time have been able to research multiple subjects. Long term monitoring studies are desirable by scientists but not always available due to limited resources. Fortunately this is not the case for researchers at SRS, as they have successfully published over 50 documents in 13 years. SRS studies have contributed much knowledge to many scientific disciplines (landscape ecology, dispersal & invasion ecology, ornithology, entomology and mammology) with regards to corridor dispersal and are directly contributing to conservation efforts of endangered species locally in North Carolina.

6.2.4 One-off Studies

Compared to the Calling Lake experiments and those originating from SRS, questions may arise as to what one-off studies may offer. As desirable as long term studies are, they are also scarce. One-off studies have as much potential to impact the scientific community if not more. Long term studies like SRS are exceptional at standardization of variables but limited to one habitat and minimal species diversity Gilbert-Norton et al. (2010). One-off studies conducted around the world bring about this diversity and provide new information to the scientific community.

6.3 Discussion Topics Chapter 5

6.3.1 Implications of Results towards Nature Conservation

Conservation planning is the consideration, conscientious planning and execution of approaches to address natural systems and ecological processes that sustain Earth's natural resources (United States Department of Agriculture n.d.). Conservation planner is the title given to individuals responsible for the management of natural resources and issues related to those resources. Conservation planners have the task of balancing environmental needs with human economic and social needs. To obtain conservation goals many of the main tasks and responsibilities bestowed upon conservation planners include:

- The acquisition of land for conservation;
- The interface between government bodies, collaborating organizations; stakeholders, the public and policy makers, with consideration to conservation initiatives
- The planning and initiation of research projects
- The planning and initiation of ecological restoration programs
- Ecological consultancy
- Report writing and funding efforts

The implications of this thesis can directly assist conservation planners in two ways. The first is by facilitating influential information on past experimental corridor research and the second, by providing planners with new advancements in technology for appropriate conservation tasks. By performing a literature review I have identified the 'parameters' around corridor experimentation. These 'parameters' are the extent of experimental corridor research from its inception in the early 1990's to the current state of corridor research. This thesis is a condensed historical evaluation of corridor research with emphasis on experimental design, methods used, taxa studied, experimental locations, environments utilized and spatial and temporal scale. Conservation planners may utilize the information provided in this review to appropriately structure corridor research and networking strategies to accomplish desired goals or to answer corridor related questions. By my reporting on technological advancements and methods (originating from or utilized for corridor experiments) as well as addressing their practical application towards land management, ecological restoration and stewardship initiatives, conservation planners can be informed of new options available to them to initiate best management practices (BMP).

6.3.2 Implications of Results towards Research

Implications of this thesis's results towards future research are two-fold. By conducting a literature review of the most recent experimental corridor literature I have identified research gaps that may provide future research opportunities. Also from extensive research I can suggest appropriate monitoring methods for future researchers, which may improve future research practices.

6.3.3 Research Gaps

A result of this literature review has led to the identification of one gap in the research, being a lack of diversity in habitat types. Of the 28 studies reviewed, experimental habitat types were limited to forest and grassland environments (with exception for Castellon & Sieving (2006)). If future research does not expand to incorporate more heterogenous landscapes, science will be unable to evaluate the movement dynamics of species in more diverse landscapes.

The majority of plantation forests in the world are planted for timber production. Plantation forests are by definition "planted". Management practices for the forestry industry generally utilize methods that will maximize system outputs (timber) for economic gain. To obtain such outputs, management practices such as tree pruning, set tree spacing and understory suppression are employed, which result in a homogenous landscape. This invariable landscape that is void of a shrubby understory thus has the potential to be used to monitor dispersing animals.

Of the 18 experiments conducted in forested landscapes, 14 were conducted at one site in a Loblolly and long leaf pine plantation (U.S.A.), one in a Douglas fir forest (U.S.A.) and 3 in a mixed boreal forest in Canada.

The difference in habitats between patch, corridor and matrix was determined not by spatial scale, but by experimental design layout. For Rosenberg et al. (1998), which took place in a Douglas fir forest, there was differentiation between matrix and patch/corridor habitat with regards to surrounding leaf litter but due to the limitation of movement to the confined patch corridor area, matrix habitat was irrelevant (Figure 18). The Calling Lake experiments on the other hand had substantial differences between the forested corridor and patches compared to the barren open soil matrix. The Savannah River Site (SRS) was unique in its experimental design, as it utilized pine forest as the matrix and successionary growth of shrubs, grasses and sedges as habitat for patches and corridors.

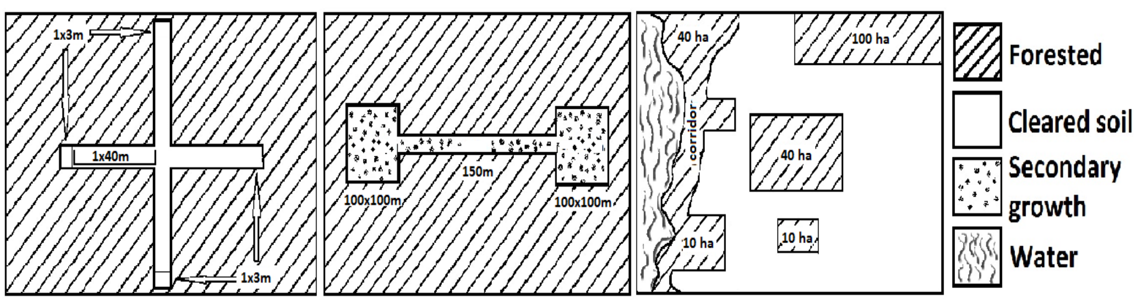

Figure 19 Experimental design layout & corridor, patch and matrix habitat. (left) represents Rosenberg et al. (1998), (middle) represents design layout of the Savannah River Site (SRS) and (right) represents studies conducted at Calling Lake in Alberta, Canada.

Of the habitat types that were utilized in the 28 corridor experiments included in this study, those that took place in grassland environments probably had the greatest species diversity within the patch, corridor and matrix compared to studies in plantation forests. Only 9 of the 28 studies were conducted in grassland environments with 4 studies conducted in different locations within the U.S.A., 2 studies conducted in Sweden, and 3 studies carried out in Norway. All grassland studies used cut grass area to represent the matrix, leaving an uncut grassy habitat as corridor and patch areas. It is unclear as to the level of diversity or the conditions of all the grassland environments used for these experiments.

There are acknowledged difficulties associated with diversifying landscape habitats. Establishment of a corridor experiment is dependent on numerous variables. In some cases, the desired taxa to be studied may or may not be available for relocation. Similarly, the environmental habitat that is desired to host the experiment in may or may not be available for modification. For example, if the taxon or habitat to be studied is categorized as endangered or environmentally significant by legal or cultural standards, then the level of manipulation will need to be adapted to suit.

Of the 28 corridor experiments reviewed, 16 studies utilized trans-located taxa and two studies used a combination of both trans-located and resident taxa. It is my assumption that many of the experimental habitats, that utilized trans-located taxa, may have been selected based on the accessible and facile ability to be manipulated and their ability to monitor taxa movement.

In order for scientists, researchers, conservationists and land managers to continue to benefit from corridor research, it is necessary for future researchers to expand on the ecosystems and study taxa they utilize. If future corridor research does not expand to other ecosystems it will limit the ability of scientists to understand how corridor related dispersal might operate in other systems with other species (Gilbert-Norton 2010). What scientists will gain will be a holistic understanding of species-system dynamics that may eventually assist land managers and conservation planners with the knowledge required to restore and conserve ecosystems, species and genetic information for future generations.

6.3.4 Suggested Methods for Future Researchers

When performing experiments in more diverse landscape habitats, best management practices should be employed to minimize adverse impacts on sensitive environments. Scientific researchers and conservationists are currently studying and working on the conservation of the St Francis Satyr butterfly around Fort Bragg, in North Carolina (U.S.A.). Scientists here have been implementing ecosystem-sensitive methods for monitoring species within a heterogenous landscape. These methods utilize a combination of both in-complex and technological advancements for the collection of species information and include:

- Direct observation
- Use of line transects for vegetation survey and species movement
- Mark release recapture (MRR) for demographic information, population size and tracking capabilities
- Computer software modeling for spatial range, dispersal through corridors to other subpopulations and gamete dispersal

The utilization of combined non-invasive monitoring methods can alleviate anthropogenic pressures on wildlife and ecosystems, allowing study taxa to interact in a more natural manner. Other non-invasive methods exist, other than the ones provided above. For more information on the St. Francis Satyr butterfly see Bartel et al. (2010), Haddad (2006), Haddad (2008), Hudgens (2002) and Hudgens et al. (N.D.).

For future experimental corridor research that will require habitat manipulation or alteration, restoration efforts should be mandatory for any altered natural habitat. The restoration process may in turn serve as a potential source for further experiments. It is understood that this option is not always available to most researchers. Extensive collaboration, planning and funding are all required to commence a project of this nature. The benefits of establishing a collaborative project are twofold.

- Support and sponsorship of long term restoration project
- Ability for scientists to work directly with land managers, and to document successional changes and their effects on movement patterns of study taxa

Examples of such a collaborative project are the corridor experiments being conducted at the Savannah River Site in North Carolina (U.S.A.). Researchers from University of North Carolina and other universities around the country are collaborating with the United States Forest Service, other government bodies and many conservation organizations to research, conserve and restore important habitat for local endangered species.

6.3.5 Implications of this Research on a Global Scale

The information in this thesis can be restructured to discuss how data obtained from experimental corridor research has advanced ecological modelling software. Ecological modelling is a necessary tool that allows researchers the ability to make predictions about potential outcomes associated with changing parameters of a particular system. The benefit of modelling software is the circumvention of excessive expenditure of finances and resources that would normally be required to conduct an actual experiment. Ecological modelling software is appropriate for researching large spatial scales with various landscape compositions and configurations, which would generally be difficult to experiment on. Ecological modelling software would also serve as an important source of information when relevant information is demanded immediately. Quality ecological experiments may often take years to accumulate sufficient data to be able to draw sufficiently usable conclusions from. Models utilize data from previous and on-going experiments and manipulate the data to form hypothetical results than can be used to infer consequences to given actions.

Ecological models also have the potential to calculate many species-habitat interaction outcomes with appropriate input data, such as information about landscape parameters, study species, and ecosystem functions or outer influences (e.g. disturbances). Species input data generally includes population parameters, behaviours and life history traits.

Ecological models are enhanced by data collected by direct observation and experimentation of various species within various landscape types. The future and use of ecological modelling to be applied to various landscape types is somewhat restricted by the limited habitats experimental corridor research has been conducted in. This limitation could greatly affect conservation efforts to target “unique” ecosystems around the world.

Future researchers need to take this into consideration when conducting corridor experimentation in more diverse landscapes. Results from this literature review has identified a concentration of studies conducting research in two habitat types, forest and grassland environments. For a global advancement of ecological modelling software, improvements are to some degree dependent on the diversification of input data.

In summary, the implications of this research towards nature conservation have the potential to influence conservation planners and land managers with land planning and restoration planning initiatives, assistance with experimental corridor design and networking options. Contributions towards academia include new directions for experimental corridor research and reference to methods that can be applied to research endangered species in sensitive ecosystems. Reconstitution of this document and future publication by a reputable scientific journal may contribute to the knowledge base of experimental corridor research currently available.

7 Conclusion

Based on the findings from this review of the experimental corridor literature, wildlife corridors do facilitate biotic movement and are a relevant conservation tool to mitigate the negative effects of fragmentation. This review was carried out to report on the 'practice' of corridor experimentation which has existed for only 22 years. The aim of this research was to investigate empirical evidence derived from the literature of experimental corridor research that support or negate the utilization of wildlife corridors as conduits for biotic movement. Listed below are the four objectives:

1. Conduct a review of "Experimental" corridor literature published over the last 17 years (1993-2010).
2. Compare and contrast experimental variables including; methodological design, taxa studied, spatial and temporal scales as well as results.
3. Create a methodology to identify quality scientific evidence of corridor-dispersal function.
4. Examine the extent to which these experiments have contributed to nature conservation.

Two experimental corridor documents were identified that both supported corridor efficacy in facilitating biotic movement. Haddad's (1999) document supported the use of corridors with his study on the movement patterns of two butterfly species through corridor connected habitat in a large scale corridor experiment. Results from Collinge (2000) also supported the function of grassland corridors on one of three species, in a similar large scale experiment. Both documents scored 100% through the Ten Criteria for Experimental Documents.

Personal communication with both authors about their work's direct contributions towards nature conservation resulted in identifying the progression of further research from only one author, Dr. Nick Haddad. Haddad (1999) was the first of many experiments conducted in a large scale landscape manipulation experiment site, Savannah River Site (SRS), located near Aiken, North Carolina (U.S.A.). Nearly 50 documents (since 1999 to 2012) have been published regarding corridors, edge effects, fragmentation and demographic variables of endangered species all associated with SRS. Their studies have contributed to advancements in technology such as new seed dispersal tracking methods and development of ecological modelling software that are being utilized outside SRS.

Experimental wildlife corridor research is beneficial to the advancement of scientific research within corridor ecology. Data collected from corridor experimentation has and will continue to influence the progression of ecological modelling software, which are the ecological tools for the future. The capabilities ecological modelling provide, allow researchers to address potential environmental threats before they become problematic. These tools are enabling the conservation of ecosystems, species and genetic information for future generations.

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