RESEARCH PAPERS

The Condor 113(4):713–723

FORTY-FIVE YEARS AND COUNTING: REFLECTIONS FROM THE PALOMARIN FIELD STATION ON THE CONTRIBUTION OF LONG-TERM MONITORING AND RECOMMENDATIONS FOR THE FUTURE

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Abstract. Long-term monitoring is essential to understand the effect of environmental change on bird populations. Ornithological field stations that have recorded detailed demographic data on bird populations over decades are well positioned to make important contributions to emerging research questions. On the basis of our experience at PRBO Conservation Science's Palomarin Field Station and a review of the literature, we assess the ability of field stations to use their long-term data to address current and future issues in conservation and management. We identify barriers to the application of data from field stations as well as some of the unique contributions made by these stations, and we present recommendations regarding the development, maintenance, and enhanced application of long-term data.

Key words: *climate change, demography, field station, long-term monitoring, Palomarin.*

Cuarenta y Cinco Años y Contando: Reflexiones desde la Estación de Campo Palomarin sobre la Contribución del Monitoreo de Largo Plazo y Recomendaciones para el Futuro

Resumen. El monitoreo de largo plazo es esencial para entender los efectos de los cambios ambientales sobre las poblaciones de aves. Las estaciones de campo ornitológicas que han registrado datos demográficos detallados de poblaciones de aves a lo largo de décadas están bien posicionadas para hacer contribuciones importantes para preguntas emergentes. Con base en nuestra experiencia en la Estación de Campo Palomarin de Ciencias de la Conservación y en una revisión de la literatura, determinamos la capacidad de las estaciones de campo de usar sus datos de largo plazo para abordar problemas actuales y futuros sobre conservación y manejo. Identificamos las limitantes para el uso de los datos de las estaciones de campo, así como algunas de las contribuciones únicas hechas por estas estaciones, y presentamos recomendaciones con relación al desarrollo, mantenimiento y la aplicación mejorada de datos de largo plazo.

INTRODUCTION

Bird populations worldwide have faced growing threats over the last century, and extensive effort has been devoted to understanding the causes and documenting the consequences of these threats (Robbins et al. 1989, Brown et al. 2001, Sanderson et al. 2006). In light of the rapid environmental changes that are now underway, the need for long-term data and monitoring are greater than ever (U.S. NABCI Monitoring Subcommittee 2007, Wiens 2008). Long-term data can help us understand baseline ecological processes, provide a context for unexpected changes, quantify the processes that drive trends, test and validate projections, and provide guidance to future research.

Long-term ornithological data sets vary in scope, scale, and objectives and span time frames from a decade to well over half a century (e.g., Isle of May Bird Observatory, founded in 1934; Fair Isle Bird Observatory, founded in 1948; Long Point Bird Observatory, founded in 1960; Powdermill

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The Condor, Vol. 113, Number 4, pages 713–723. ISSN 0010-5422, electronic ISSN 1938-5422. DOI: 10.1525/cond.2011.100214

Nature Reserve bird-banding program, founded in 1961; Breeding Bird Survey, initiated in 1966; Manomet Bird Observatory, established in 1969). Some of these data sets are broad in extent, arising from a single method employed over a large geographic scale. For example, the Breeding Bird Survey (BBS; Sauer et al. 2008), Monitoring Avian Productivity and Survival (MAPS; DeSante et al. 2001), and Resident Bird Census (RBC; Gardali and Lowe 2006) programs are systems of collecting point-count, mist-netting, and spot-mapping data, respectively, across North America. Historic accounts and museum records can also be used to construct, or contribute to, "nontraditional" long-term data sets (e.g., Patten et al. 2010). Other long-term data sets are more focused, often involving intensive study of a single population at a single location, such as studies documenting long-term demographic patterns for the Song Sparrow (*Melospiza melodia*; Nice 1937, Smith et al. 2006), Large Cactus Finch (*Geospiza conirostris*; Grant and Grant 1989), and Great Tit (*Parus major*; Perrins 1965, Garant et al. 2005), or those based on a particular theme or behavior (O'Connor 1991) such as cooperative breeding (e.g, Koenig and Mumme 1987, Woolfenden and Fitzpatrick 1990). A third type of long-term data comes from ornithological field stations or bird observatories (hereafter, field stations), which often use multiple methods to collect detailed demographic data on a local community of species. Examples include Powdermill Nature Reserve (Rector, Pennsylvania; e.g., Clench and Leberman 1978, Mulvihill et al. 2004), Long Point Bird Observatory (Port Rowan, Ontario; e.g., Francis and Hussell 1998), Manomet Center for Conservation Sciences (Manomet, Massachusetts; e.g., Lloyd-Evans and Atwood 2004), and the Hubbard Brook Ecosystem Study (North Woodstock, New Hampshire; e.g., Holmes and Sherry 2001).

Although well-documented, long-term data sets may be invaluable resources for investigating how species and communities respond to environmental change, many of these data sets remain under-utilized. For example, investigations into species' responses to climate change have been dominated by species-distribution modeling, an approach that makes use primarily of presence/absence data from the broadest data sets to document and project changes in species' ranges (e.g., Root 1988, Hitch and Leberg 2007, Stralberg et al. 2009). Although these data are essential to understanding the scale and magnitude of such changes, they do not address the underlying demographic mechanisms of population change (Saracco et al. 2008). More in-depth studies detailing fecundity, survival, and movement, such as those available from field stations, are a necessary complement (Sæther et al. 2004, Seavy et al. 2008). We argue that, whether becuase of a lack of personnel or funding, biases against monitoring, or simply the difficulty of accessing the data, long-term data from many field stations are not being used to their full potential.

The Palomarin Field Station (hereafter, Palomarin), founded in 1966 by the Point Reyes Bird Observatory (now PRBO Conservation Science; hereafter, PRBO), is the site of one of the longest continuously running data sets on landbird demography in North America. Through 45 years of operation, Palomarin and its data have contributed to a range of studies that include investigations of life history, demography, and climate change, as well as the development, improvement, validation, and exportation of many field methods. Even so, the full value of the data sets from Palomarin and similar institutions is not fully appreciated. In this paper we review the literature pertaining to long-term sets of bird-monitoring data and the contributions of field stations. We use our experience and knowledge from Palomarin as a case study to illustrate how long-term datasets can be applied to emerging research questions, and we identify characteristics that can facilitate this flexibility. We also identify a few of the many ways in which field stations make unique and valuable contributions to science through approaches that are not often possible or prioritized in other settings. Finally, we offer recommendations drawn from lessons learned at Palomarin to encourage dialogue on how the contributions of field stations to avian ecology and conservation can be maintained and improved, particularly as climate change and its consequences bear down upon us.

CONTRIBUTIONS OF FIELD STATIONS

LITERATURE SURVEY

To identify the contributions of field stations to ornithology, we review published articles, white papers, and other resources that used data or results from Palomarin. We supplemented the Palomarin review by consulting other literature for several long-term ornithological field stations around the world. Although we draw examples from a variety of field stations, we focus on Palomarin as a case study because we aim to draw attention to the scientific products of field stations as well as to the challenges of ensuring flexibility and accessibility of data to address emerging questions, and our familiarity with Palomarin makes this possible.

EMERGING QUESTIONS AND NEW OBJECTIVES

The data gathered at field stations often start with a set of objectives, but the uses of these data evolve over time as the data set grows, as unforeseen conservation challenges emerge, as new statistical methods are developed, and as new questions in ornithological research arise. For example, the initial goals of many monitoring programs often involve simple assessments, inventories, and documentation of life-history patterns such as the timing of migration (e.g., Hussell et al. 1967, Ralph 1971). As these data sets grow, their value in addressing new questions becomes apparent. With data on the scale of generations rather than breeding seasons (Sæther et al. 2005), long-term trends and rare events (e.g., sudden reproductive failures) can begin to be separated from normal annual variation. There are numerous examples of studies detailing trends in bird populations, including some from Palomarin, (DeSante and Geupel 1987), Hubbard Brook (Holmes and Sherry 2001), Powdermill Nature Reserve (Hagan et al. 1992) and the Manoment Center for

Conservation Sciences (Lloyd-Evans and Atwood 2004). Documenting trends in abundance can be used to identify species of conservation concern as well as to indicate potential avenues for conservation and management (e.g., Strong et al. 2004).

Data detailing changes in the vital rates underlying population trends are particularly valuable. For example, studies in the late 1990s raised concern over declining populations of neotropical migrants, and data from field stations were then used to investigate whether a decline in reproductive success or survival (and therefore loss of breeding or winter habitat) was the primary source of the declines (Gardali et al. 2000, Holmes 2007). Studies at field stations have also documented annual variation in survival and productivity of several species of seabirds (e.g., Ainley and Boekelheide 1990, Harris et al. 1994) and have contributed to our understanding of the sensitivity of these vital rates to weather and oceanographic variables (Harris and Wanless 1990, Frederiksen et al. 2008).

As concern about the effects of climate change has grown, data from many field stations have been used to investigate the effects of weather on populations. Daily weather data have long been collected at Palomarin, with the initial rationale of investigating how variation in weather might affect migration. Thirty years later, these data permit an examination of the effects of variation in weather on reproductive success (Chase et al. 2005) and survival rates (Dybala, unpubl. data). Data from Palomarin and the Ottenby Bird Observatory in Sweden have been used to elucidate the role of large-scale, decadal climate variations in affecting population dynamics (Ballard et al. 2003, Stervander et al. 2005). Regional phenological shifts in response to temperature change and large-scale climate oscillations have also been documented at several field stations, such as the Eyre Bird Observatory in Australia (Chambers 2005), Powdermill Nature Reserve (Marra et al. 2005, Van Buskirk et al. 2009), Long Point Bird Observatory (Mills 2005), San Francisco Bay Bird Observatory and PRBO (MacMynowski et al. 2007), and Manomet Center for Conservation Sciences (Miller-Rushing et al. 2008). Combined with climate projections, demographically detailed data from field stations have been used to predict species' response to climate change (Wolf et al. 2010). Although the founders of PRBO did not foresee that the monitoring protocols they were establishing would one day be used to address issues such as climate change (C. J. Ralph, pers. comm.), these long-term data have become an increasingly important resource for investigations into the effects of climate change on bird populations (Seavy et al. 2008) and other emerging ecological questions.

It is this capacity for historic data to be used to shed light on emerging conservation concerns that makes these long-term monitoring stations so important, especially when the complexity of the processes involved makes decades of high-quality data a necessity. What makes this flexibility possible is the maintenance of standardized protocols for data collection and curation. Although the use of data for purposes other than testing a priori hypotheses is often criticized (Yoccoz et al. 2001, Nichols and Williams 2006), the flexibility of well-documented, repeatable methods, combined with the long time scale over which data are collected, makes these data a powerful tool for addressing new questions (Hochachka et al. 2007, Kelling et al. 2009, Lindenmayer and Likens 2009). The depth and breadth of standardized, multi-method, multi-species monitoring from field stations provide a unique perspective on research questions that cannot be obtained from short-term field experiments or presence/absence data.

UNIQUE CONTRIBUTIONS TO ORNITHOLOGY

Field stations can also contribute to ornithology in several ways that are not generally assigned a high priority by other organizations or institutions. For example:

Natural history. Natural history is a foundation of ecological and evolutionary investigations, yet it is often undervalued by the scientific research community (O'Connor 1991, Herman 2002, Villard and Nudds 2009, Beehler 2010). Field stations have been instrumental in promoting continuing natural-history inquiry and documentation. Repeated observations by hundreds of biologists at the same study site can result in a wealth of information about basic biology that enriches our understanding of and appreciation for birds while informing and advancing research. For example, field stations have made important contributions to knowledge about the timing of migration (e.g., Howell and Gardali 2003), breeding phenology (Geupel and DeSante 1990), home ranges (e.g., Baker and Mewaldt 1979), and nest-site selection (e.g., Stewart 1973). Building on careful observation of patterns and variation in plumage characteristics, Palomarin biologists have developed techniques for aging and have advanced our understanding of the molt cycles of landbirds (Stewart 1971, Yanega et al. 1997, Flannery and Gardali 2000, Cormier et al. 2003, Howell et al. 2003). Combined with data from many other field stations, such as Powdermill Nature Reserve, and museums, such as the California Academy of Sciences, these data made significant contributions to the *Identification Guide to North American Birds* (Pyle et al. 1987, 1997), an essential reference for those handling landbirds. There are many more opportunities for field stations to contribute to natural history, and we should continue to value this type of contribution.

A platform for collaboration. Beyond their own long-term monitoring, there are several ways in which field stations can serve as platforms for collaboration. In addition to data-sharing and collaborative analyses (discussed below), field stations can facilitate research by providing facilities and field-site access to outside researchers and graduate students. Such partnerships can bring new analytic methods to existing data collection, as well as result in new applications that extend the domain of field-station data beyond the initial objectives. Examples include application of molecular techniques to validating morphological methods of aging and sexing raptors with capture data from the Golden Gate Raptor Observatory (Pitzer et al. 2008) and hybridization of chickadees (*Poecile* spp.) at Hawk

Mountain (Reudink et al. 2007). At Palomarin, research has addressed the effect of Brown-headed Cowbird (*Molothrus ater*) parasitism (Trail and Baptista 1993), the differences in energetic expenditure across an altitudinal gradient (Weathers et al. 2002), and the effects of ectoparasites and disease vectors on landbirds (Super and van Riper 1995). Field stations can also collaborate through data sharing, which can broaden the applicability of single-site monitoring (see below).

Outreach and communication. Field stations have a unique opportunity to communicate research, results, and an appreciation for birds and their natural history directly to the public. Field stations allow the public to directly observe field methods in progress and show the utility and importance of long-term data collection. At a time when many primary and secondary schools are losing opportunities for experiential education, organizations such as the Klamath Bird Observatory, Rocky Mountain Bird Observatory, Alaska Bird Observatory, Manomet Center for Conservation Sciences, Powdermill Nature Reserve, and PRBO offer demonstrations of mist netting and other educational programs for school groups. Since 1998, some 9000 students have visited Palomarin in organized field trips to see mist netting in action (M. Wipf, pers. comm.). Mist netting and banding can be extremely powerful tools for education and outreach because they allow people to see wild birds in the hand and observe first-hand how populations are studied (Trombulak 2009). In this way, long-term research and monitoring stations can provide an essential connection between science and the public that is often absent (Pitkin 2006).

Beyond formal education and outreach programs, the physical presence of a field station can increase the representation of science in a community. By participating in local events and inviting residents and agency managers to drop in and observe field methods, field stations create a scientific presence that can work to increase environmental awareness and science literacy. Such an effect is difficult to measure, but a recent survey of environmental decision makers showed that one-on-one communication with ecologists is valued almost as much as peer-reviewed publications and synthetic reviews, though such interactions tend to be less readily available than other communication methods (Seavy and Howell 2010). Field stations are an excellent setting for such face-to-face interaction.

LESSONS LEARNED: ADVICE TO ORNITHOLOGICAL FIELD STATIONS

There is no single prescription or set of methods that can be applied to all monitoring programs; each program must be designed and modified according to its goals and constraints (Lindenmayer and Likens 2009). Still, there is much that long-term research and monitoring stations can learn from one another. Here, we offer several recommendations drawn from lessons learned through 45 years of monitoring at Palomarin. By sharing these recommendations, we hope to encourage the continued development, maintenance, and application of long-term monitoring datasets and reinforce the value and role of field stations.

1. Explore diverse opportunities for funding: Perhaps the greatest obstacle to long-term monitoring stations is the financial cost of their establishment and maintenance (Caughlan and Oakley 2001). Most research funding is available on a 1- to 3-year basis, which may encourage rapid and regular publication of research but can discourage the investigation of long-term processes. Limited exceptions exist, such as the National Science Foundation's Long Term Ecological Research and Long Term Research in Environmental Biology programs (Callahan 1984, Collins 2001). Other sources of funding can include endowments developed from individual donors and contracts with state and federal management agencies. The collection of data over four decades at Palomarin has been made possible by funding from a diverse group of supporters, including foundations and individuals interested in monitoring, conservation, education, and outreach, as well as through state and federal funding. Efforts to extend Palomarin's base of support among individuals and partners through an active outreach program have enabled the maintenance of long-term monitoring at Palomarin.

2. Develop a strong internship program: The fostering, training, and development of field biologists have been a fundamental part of the goals and operations at Palomarin. Internships form a critical bridge between academic training and professional employment while simultaneously contributing to the collection of long-term, standardized monitoring data. Since 1966, nearly a thousand seasonal biologists have received training and contributed to data collection at Palomarin. A recent informal survey found that 90% of the biologists who interned at Palomarin from 1996 to 2006 went on to continue working in conservation and/or to pursue a graduate degree (Howell 2006). Internships teach field-based research skills, such as banding and nest searching, that prepare young biologists for careers in research, conservation, and wildlife management. Internship programs also educate seasonal biologists beyond teaching the fundamentals of field research by involving them in data management. This teaches the basics of manipulating and working with large data sets and reinforces the value of the highest standards of data quality. Encouraging critical thinking through regular discussion of the relevant literature allows interns to understand the field and how their work contributes to overarching questions and research goals (Gardali 2006). Offering opportunities to participate in the development of analyses and methods exposes them to the next steps of the scientific process and can result in publications (e.g., Johnson and Geupel 1996, Cormier et al. 2003, Samuels et al. 2005). It takes a significant investment of time and energy to mentor interns (Gardali 2006), but repeated exposure to new students can inspire supervisors, provide opportunities for regular review and improvement of the station's procedures, and help generate novel ideas for research. Such efforts also are good investments in the future, as "alumni" who move on to work with partner organizations and agencies can create new opportunities for collaborations and help build the reputation of a field station as a valuable training center.

3. Use multiple monitoring methods: Because no single method will likely capture information on all ecological processes of interest, and because even a well-designed study can suffer from the use of a single sampling method with no ability to test assumptions or validate the results, we advise using several methods in tandem. Multiple monitoring methods can be used to examine different but complementary objectives (Fig. 1). For example, we can assess trends from surveys of population size and examine primary demographic data (e.g., productivity and survival) to determine the key variables responsible for population increases or decreases. Hence, a multi-method approach can provide managers with more useful information on which management and research priorities can be based (DeSante and Rosenberg 1998).

At Palomarin, demographic data obtained though mist netting are supplemented locally by spot mapping and nest searching and regionally by point counts. Using multiple methods at a single site has allowed researchers to test the accuracy, repeatability, and potential biases of each method (DeSante 1981, Silkey et al. 1999, Jennings et al. 2009). For example, Ballard et al. (2004) showed that the frequency of mist netting affects the accuracy of productivity measures and that the optimal frequency of netting varies by species.

4. Measure relevant environmental and ecological variables: Data detailing trends in demographic variables can often provide important insights into possible mechanisms, particularly when combined with data on related factors such as

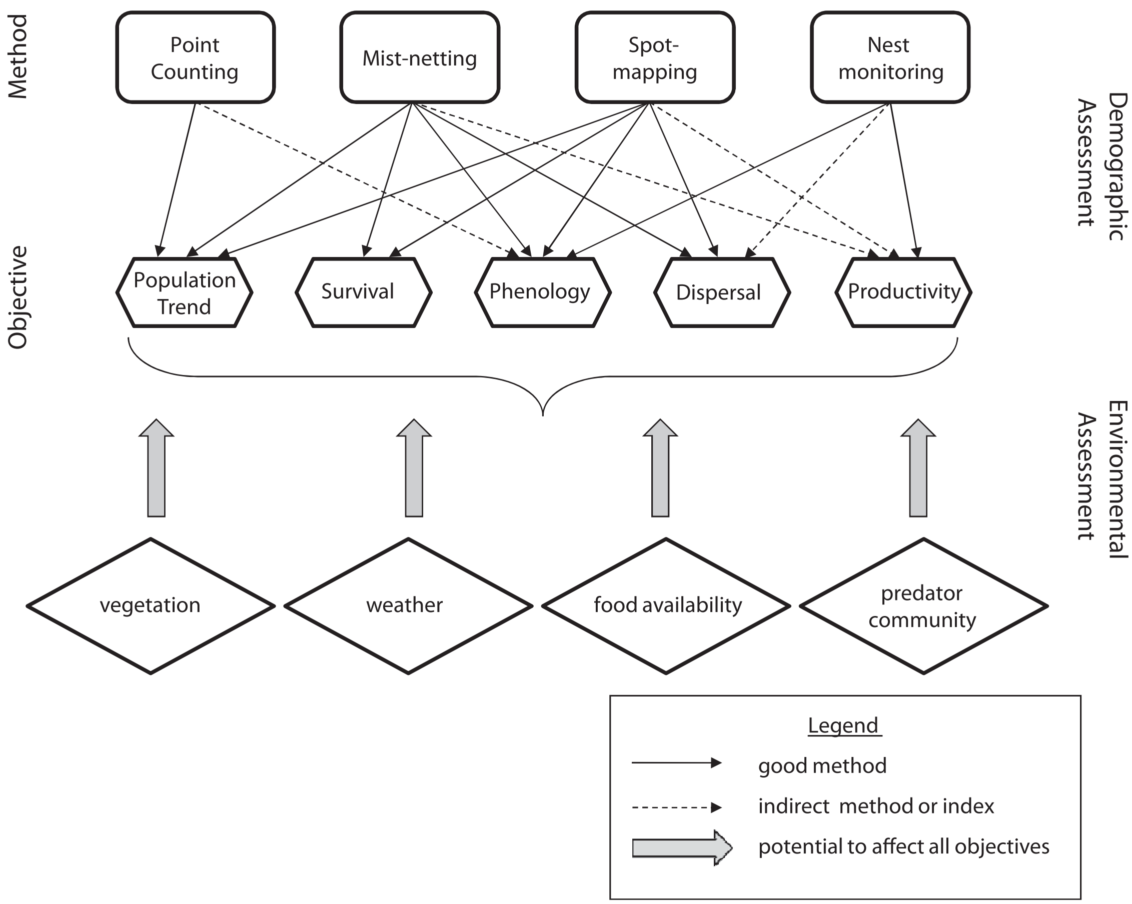

FIGURE 1. The use of multiple monitoring methods allows for the estimation of multiple demographic measures, as well as providing a way to validate results within a single site. For example, both spot mapping of color-banded birds and mist-netting data can provide estimates of survival but may sample different populations within the same area (e.g., territorial breeders vs. a mixture of local birds and transients passing through). A comparison of survival as estimated by the two methods can reduce uncertainty in the estimates, as well as help to identify potential biases of each method (e.g., Nur et al. 1999). Adding data on environmental variables can provide additional insight into the sources of variation within each demographic variable (e.g. Chase et al. 2005).

weather, predator abundance, food availability, and vegetation (Fig. 1). Local weather data have been used to show strong relationships between rainfall and reproductive success in the Song Sparrow (Chase et al. 2005). Annual vegetation transects have documented a continuing plant-community transition from coastal scrub to Douglas-fir (*Pseudotsuga menziesii*) forest, an important local process affecting changes in the bird community (E. Porzig, unpubl. data). Although data on weather and vegetation are undeniably useful, Palomarin and other stations would likely benefit by adopting methods employed at other sites of long-term research, examining additional environmental variables, such as insect availability (Perrins 1991, Cresswell and McCleery 2003, Nagy and Holmes 2004, 2005) and plant and insect phenology (Peñuelas et al. 2002). Such extensions will become especially germane in light of the potential effects of climate change on community dynamics, migration phenology, and trophic cascades.

5. *Rigorously standardize and document methodology:* Detailed recording and adherence to methods is perhaps the most important step to ensuring repeatability and allowing for the potential to apply long-term data to future emerging questions. This also ensures consistency and quality of the data across many years with a constantly changing team of biologists. At Palomarin, standardization of mist netting took place gradually through the 1960s and 1970s; the methods were not fully standardized until 1979, limiting the application of the early years of data. In 1980, biologists at Palomarin developed a detailed handbook (www.prbo.org/cms/docs/terre/PaloHandbook2006.pdf) that thoroughly describes all methods used at the station. By serving as training manual and reference for all field staff, it has significantly improved the quality and standardization of data collection.

6. *Regularly assess and evaluate methods:* Much of the value of long-term stations lies in the temporal scope of monitoring and data collection. Often, the increasing value of a sampling method as data accumulate can lead to the justification of continuing data collection "for history's sake." However, to maintain effective and efficient monitoring, the cost of continuing a protocol should be regularly weighed against that of redirecting resources toward a different area (Caughlan and Oakley 2001, McDonald-Madden et al. 2010), or perhaps even adopting a different protocol (Lindenmayer and Likens 2009). The legacy of the data set must be balanced with the resources required to maintain that data set, as well as the potential for future application of those data to address emerging questions. At the same time, if efficiencies are found and/or funding allows, field stations should consider expanding the types of data they collect in order to better address emerging ecological questions and conservation challenges.

The decision to change a protocol or not has often been the source of debate at Palomarin because of the potential to affect future but unanticipated applications of the data. Lindenmayer and Likens (2009) proposed a framework for adaptive monitoring that includes steps for evaluating and changing methods. Other methods assessments might include using data simulations to test the effect of changing a method on the detection of specific processes or periodically convening a panel of external experts to review the station's methods. If protocols are to be changed, efforts should be made to gather the appropriate information to allow for cross-referencing with new protocols or other methods.

7. *Maintain data quality and accessibility and follow best practices in data management:* Maintenance of correct and accessible data facilitates timely analysis and application, and following best data-management practices ensures the long-term security and utility of the data. "Best practices" include many considerations (reviewed by Martín and Ballard 2010). For example, data should be entered and verified as soon as possible after collection, preferably by individuals directly involved in data collection, so that error propagation is minimized. Database structures and metadata should be well documented so that naïve users can determine appropriate uses of the data in the event that the original designers are not available to assist. Backup and recovery systems should be tested periodically. A data-sharing and publication policy (e.g., Ballard 2003) should be in place and understood by all contributing researchers. Contribution of data to online systems such as the California Avian Data Center (CADC) and the Avian Knowledge Network (AKN) makes data much more accessible to multiple users and ensures off-site backups for long-term curation as well as automated data-verification routines that have more sophistication that those typical of smaller databases (Lepage et al. 2005, Ballard et al. 2009).

8. *Explore new analytic methods:* To address complex and broad-scale ecological questions, analysis of large datasets may require the use of nontraditional analytical techniques. There are several promising new tools that allow a "data-driven" method for identifying patterns in large data sets (Kelling et al. 2009). For example, bagged decision trees and other exploratory data-analysis techniques allow sifting of hundreds of covariates to identify unexpected relationships, which can be used to develop novel hypotheses (Hochachka et al. 2007). In addition, long-term data sets often do not meet the assumptions of traditional statistical analyses. New tools, such as mixed (hierarchical) models, which provide solutions to the problem of non-independence of samples in longitudinal data (Bolker et al. 2009, Fink and Hochachka 2009), are emerging to handle these issues.

Advances in survival estimation also may be applied to long-term data sets. For example, there are many variations on mark–recapture models that provide increasingly accurate and detailed estimates of demographic rates and the factors influencing them, but such models require many years of data to be useful. Reverse-time mark–recapture models, which have been used to investigate effects of environmental variation on demographic rates and their subsequent effects on population dynamics (e.g., Nichols et al. 2000, Cooch et al. 2001, Julliard 2004, Saracco et al. 2008), are now being applied to Palomarin data (Dybala, unpubl. data). Multistate mark–recapture models allow for an examination of heterogeneity in survival rates among individuals moving between different habitat patches or transitioning between different states (e.g., successful vs. unsuccessful breeder, territory holder vs. floater) and have been used to investigate individual quality, reproductive success, and environmental conditions as factors that may influence probabilities of survival or dispersal (Lebreton and Cefe 2002, Lescroel et al. 2009, Schaub and von Hirschheydt 2009). In addition to these improvements in survival analyses, advances in analysis of nest survival allow for the incorporation of multiple causal variables as well as variation in daily survival rate (Jones and Geupel 2007).

Although many of these emerging analytical tools are computationally complex, they also incorporate increasing realism and accuracy into scientific investigations. The potential for these tools to advance understanding of the complexity of bird ecology and conservation, however, is contingent upon the quality and breadth of the data to which they are applied.

9. Strengthen the effect of single-site monitoring with collaboration and data sharing: Strategic establishment of new research sites and increased collaboration with other long-term research stations can enhance the applicability of long-term data from a single site. Single-site monitoring stations are sometimes criticized for their small geographic scope and lack of replication. However, we believe that demographically intensive and geographically extensive data both are essential to understanding how birds respond to a changing environment (Marzluff et al. 2000, Collins 2001, Hutto and Young 2002). The advantage of an intensively monitored single site is that data from nest-searching and mist-netting provide direct measurements of the processes underlying the demographic patterns of interest and thus allow insight into the mechanisms of population change. Therefore, it is especially valuable to compare single-site monitoring data to data from other long-term monitoring stations, as well as to data that capture trends on a broader scale, such as the BBS (Hagan et al. 1992, Hagan 1993, Gardali et al. 2000).

Data sharing and collaboration have immense potential for answering some of the most challenging conservation and ecological issues, such as predicting the effects of climate change on bird populations. For example, point-count data shared by PRBO, the U.S. Forest Service's (USFS) Redwood Sciences Laboratory, and the Klamath Bird Observatory resulted in a predictive analysis of the effects of climate change on species and assemblages of songbirds in California (Stralberg et al. 2009,Wiens et al. 2009). The Canadian Migration Monitoring Network has identified continent-wide trends in population indices of over 90 species, thanks to shared methods and data sharing among partner monitoring stations (Crewe et al. 2008). The European Science Foundation Scientific Network on European–African Songbird Migration identifies migration routes and phenology and investigates the ecology and physiology of birds fueling for migration (Bairlein et al. 2003).

To facilitate data sharing and collaboration, PRBO has created the California Avian Data Center (CADC), a regional node of the Avian Knowledge Network (AKN), which enables data analyses at scales greater than a single site (Lepage et al. 2005, Ballard et al. 2009). Currently, CADC hosts over 85 million observations spanning more than 40 years from a growing number of sources, including Cornell Lab of Ornithology, the Institute for Bird Populations, California Partners in Flight, the Breeding Bird Survey, Audubon California, Klamath Bird Observatory, USFS Redwood Sciences Laboratory, Big Sur Ornithology Lab, and, of course, PRBO. Data from Palomarin, originally accessible to only a relatively small audience, are now available to global data networks such as the Global Biodiversity Information Facility, thanks to major advances in informatics during the life of the database (Fig. 2).

10. Regularly publish and share results. Although it might sound obvious, it is worth recommending that the results of research and data analyses at field stations be published regularly in the peer-reviewed scientific literature. Preparing and analyzing the data for publication can elucidate a wide variety of problems with data collection and methodological inadequacies. Data preparation and analysis may also show where efficiencies in data collection could be gained. Publications establish credibility not only among peers but with current and past interns and volunteers, the general public, and policy makers (Seavy and Howell 2010). Regular publication creates a positive feedback loop. A strong publication record can help with fundraising and attract collaborators to use the monitoring data and/or augment the data sets through short-term research projects.

Sharing results with peers in publications and in scientific conferences is not enough. Other avenues are needed to reach other constituencies in order to provide information to inform and influence resource-management and policy decisions. Such avenues include organization newsletters, web-based communications, decision-support tools, press releases, planning documents, presentations, and one-on-one communications (Seavy and Howell 2010).

CONCLUSION: THE VALUE OF LONG-TERM FIELD STATIONS TO ORNITHOLOGY

As humans become increasingly aware of the complexity of ecological processes and the pervasive effects of their actions, the value of a long-term perspective on ecological patterns and variation is continually reinforced. Ornithological field stations provide valuable data on trends and variations in demographic variables over ecologically relevant time scales.

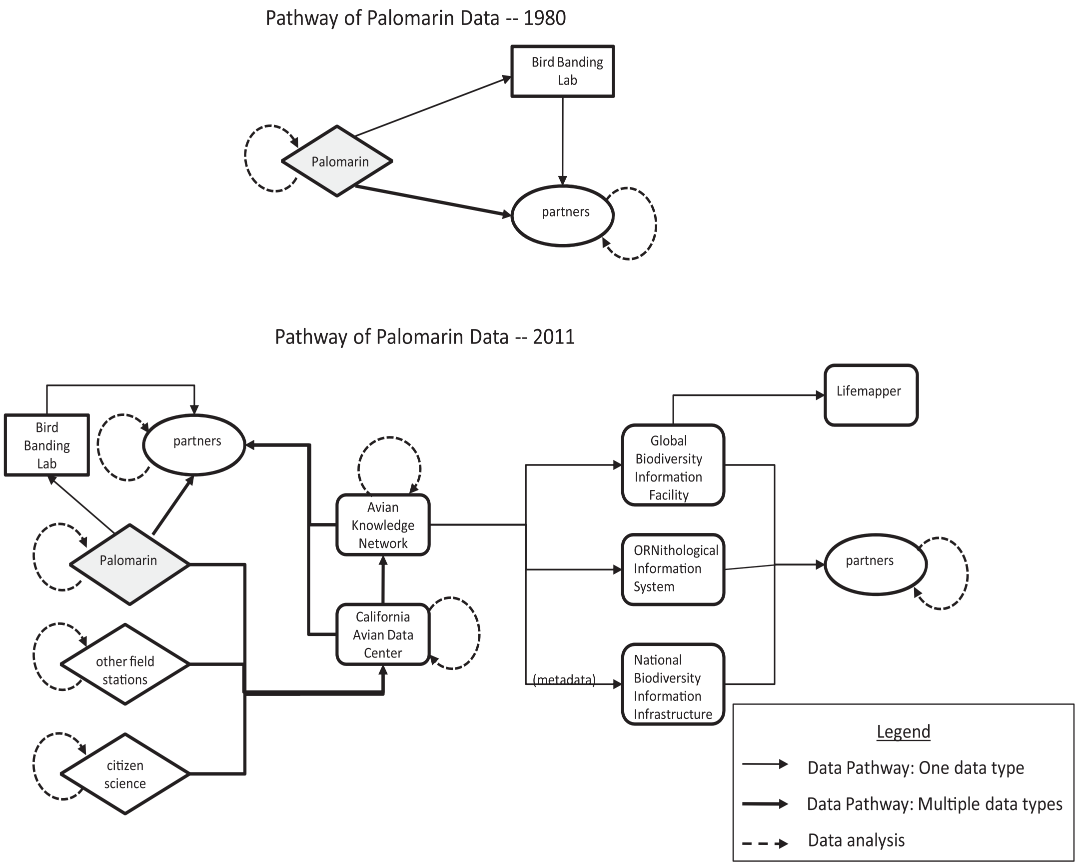

FIGURE 2. In the 1980s, data collected at Palomarin were accessible primarily to PRBO staff and outside researchers by request; data sharing was also possible through the Bird Banding Lab. Thirty years later, data from Palomarin, along with data from other field stations and citizen-science programs, are contributed to an Internet-based network, of which the California Avian Data Center and the Avian Knowledge Network are part, thus making single-site data globally accessible.

They also often act as centers for the development of monitoring and research methods, training of field biologists, public education, and facilitation of collaborative research endeavors among diverse stakeholders. Data from long-term research stations are vital to validating data from other large-scale monitoring efforts, such as the BBS (Hutto and Young 2002), and can also help to inform the design of shorter-term manipulative experiments (Krebs 1991). Clearly, long-term research stations fill a unique niche characterized by uninterrupted, detailed demographic population monitoring, development and validation of field methods, training and education of students and the general public, and productive collaboration among professionals.

The recommendations we offer here are derived from decades of trial and error at Palomarin. The challenges and enjoyment of collecting and analyzing data, sharing methods and results, and finding ways to fund these efforts continue. We hope that these recommendations will provide guidance and inspire dialogue on ways to improve the application of data from long-standing ornithological field stations. Long-term bird monitoring based at field stations will continue to provide lasting, meaningful, and essential contributions to the advancement of ornithology and avian conservation.

ACKNOWLEDGMENTS

We are grateful to L. R. Mewaldt, C. J. Ralph, and D. DeSante for establishing and maintaining long-term monitoring at the Palomarin Field Station and to the numerous interns and staff for their contributions to data collection, methods, and inspiration of the authors. The 45 years (and counting!) of monitoring have been made possible by the generous support from the members and supporters of PRBO, the PRBO board of directors, the late Dorothy Hunt, the Chevron Corporation, the Bernard Osher Foundation, the Gordon and Betty Moore Foundation, the National Park Service Inventory and Monitoring Program, and three anonymous donors. Nathaniel Seavy provided valuable insight. Steve N. G. Howell, Marcel Holyoak, and five anonymous reviewers provided useful comments on an earlier version of the manuscript. We also thank Point Reyes National Seashore for its continued cooperation and support. This is PRBO contribution number 1826.

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