# POPULATION ECOLOGY AND SOME POTENTIAL IMPACTS OF EMERGING POPULATIONS OF EXOTIC PARROTS

DOUGLAS E. RUNDE AND WILLIAM C. PITT, USDA/APHIS/WS National Wildlife Research Center, Hilo, Hawaii, USA
J. T. FOSTER, Northern Arizona University, Flagstaff, Arizona, USA

***Abstract:*** Parrots have been transported around the world since the 1400s and about 44 species have established populations outside of their native ranges. At least 70% of these introduced species were identified as potential agricultural pests, compared to only 15% of all parrot species. At least 74 exotic psittacines have been reported in the wild in the United States, but only nine species were considered established. Since 1990, 24 psittacine species have been sighted in the wild in Hawai`i, about 21 species regularly occur on the main islands and at least five appear established. Past history of successful introduction, recent status of introduced populations, and life history traits were used to identify parrots which, if introduced, appeared most likely to establish nonindigenous populations. Potential impacts related to ecology, agriculture, and health were diverse but poorly documented in the literature. Five species were the most widespread and abundant species, and were considered established. Four more species with rapidly expanding ranges and increasing populations may become naturalized. Nine species had significantly expanded ranges and increased populations. Several introduced populations remained low for 10-15 years before rapidly increasing and becoming established; similar lag periods for other psittacines have approached 30 years.

***Key Words:*** Hawaii, invasive species, parrots, psittacines.

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## INTRODUCTION

Exotic species invasions are a leading cause of native species declines and are a major environmental issue of public concern (Didhama et al. 2005). The establishment of introduced species is recognized as a major ecological threat worldwide, and increasing volumes of international trade are expected to increase the rate at which species are unintentionally transported (Ricciardi et al. 2000). Geographic and taxonomic patterns of exotic bird introductions are striking. In their analyses of 1,378 introductions of 426 bird species around the world, Blackburn and Duncan (2001a) found that 40% occurred in four geographic areas: Hawai'i (163 introduction events), New Zealand (146), mainland United States (US, 125) and Australia (113). On the 6 main Hawaiian Islands, at least 140 species of birds, belonging to 14 different taxonomic orders and originating from 6 continents have been introduced, including 75 species of gamebirds (Long 1981, Moulton et al. 2001). Taxonomic patterns of successfully established exotic birds are also distinctly nonrandom and 7 families contained more successfully established exotic species than expected by chance: Anatidae (15 species of ducks and geese), Phasianidae (35 species of pheasants), Passeridae (30 species of sparrows and finches), Psittacidae (39 species of parrots), Columbidae (19 species of pigeons and doves), Rheidae (2 species of rhea), and Odontophoridae (6 species of quail) (Lockwood 1999, Cassey 2002).

Loope et al. (2001) noted that in contrast to mainland states like Florida, inadvertent colonization of Pacific islands is highly unlikely and all successfully established exotic birds in Hawai`i were deliberately brought to the islands for some purpose. Limiting introductions therefore has relied mainly on regulating the trade in live birds and they predict that future introductions are likely to come from four groups: waterfowl, gallinaceous birds, psittacines, and passerines (especially finches). In line with this, Foster (In Press) documented that overall patterns of bird introductions into Hawai`i have shifted over time from intentional releases to escapes of birds from captivity; since 1976 this has included at least 9 psittacines.

In this paper, we highlight emerging populations of exotic parrots and review potential effects related to ecology, agriculture, and health. Few data are available from Hawai'i and we review information from naturalized parrot populations on the mainland US to identify species with increasing and expanding naturalized breeding populations, those with traits similar to successfully established psittacines (Cassey et al. 2004b) and with the potential to become agricultural pests if established.

Williamson (1996) identified 4 steps in the process of invasion of a region by exotic species as a result of human activity, and these steps have served as a basis for several subsequent studies of patterns of success for introduced birds. Blackburn and Duncan (2001a) labeled the stages of this process as "transport, introduction, establishment and spread." Usage of some relevant terms was not uniform and we followed the generalized definitions of Kolar and Lodge (2001). Indigenous species: a species found within its native range. Invasive species: a nonindigenous species that spreads from the point of introduction and becomes abundant. Nonindigenous species: a species introduced to areas beyond its native range by human activity; exotic species is commonly used synonymously. Noninvasive species are nonindigenous species that remain localized within a new environment. Established species are species with self-sustaining populations outside of the native range. Introduced birds are deemed established by the American Ornithologists Union (AOU 1998) "if there are persistent records for at least 10 years and satisfactory evidence of maintaining a reasonably stable or increasing population through successful reproduction." (i.e., not supported by continued releases). Long lifespan makes determining establishment in parrots more difficult than in other groups, but 30 species have been successfully introduced in at least one location outside of their native ranges, and introductions of an additional 14 parrot species were probably successful (Long 1981, Cassey et al. 2004a, b, Table 1).

## OVERVIEW OF PSITTACIFORMES

The Order Psittaciformes is a distinct group of birds with large hooked bills and zygodactyl feet. There are 2 families: Cacatuidae (cockatoos) and Psittacidae (parrots). Origins have been traced back to the Miocene in Queensland and Australia is considered the center of evolution and radiation for psittacines (del Hoyo et al. 1997). Diversity of parrots is highest in Australasia and South America with about one-third of all parrot species occurring in each regions. Comprehensive species accounts were compiled by Juniper and Parr (1998), Forshaw (1977), and del Hoyo et al. (1997); and online at www.arndt-verlag.com. This overview follows the taxonomic nomenclature of del Hoyo et al. (1997).

## INFLUENCES ON ESTABLISHMENT SUCCESS

Once established, the control or eradication of invasive species is highly costly, and preventing introduction and establishment is preferable (Kolar and Lodge 2001). This has prompted researchers to characterize established species in order to identify potentially invasive species before the invasion has occurred. Traits associated with invasive birds are as varied as migratory habits (Kolar and Lodge 2001), broad diet and habitat niches (Cassey et al. 2004b, c), and behavioral flexibility and forebrain size (Sol and Lefebvre 2000). Although there are intrinsic differences in the ability of bird species to invade new locations, various studies (e.g., Lockwood 1999, Sol and Lefebvre 2000) have confirmed that introduction effort, defined as the number of releases or numbers released at a location, is the principal factor influencing numbers of nonindigenous bird species.

Introduction effort is correlated with many variables previously thought to influence establishment success (Blackburn and Duncan 2001a, b), and highlights its importance both within and across large regions including oceanic islands (Cassey et al. 2005). Moulton et al. (2001) found a significant relationship between introduction effort and success rates of Galliformes (game birds) introduced to the Island of Hawai`i. Even though successful establishment ultimately depends on the particular combination of a species and a location (Blackburn and Duncan 2001a, b) this consistent finding regarding introduction effort suggests that fewer species will become established if the number of releases or number of individuals is minimized.

The Wild Bird Conservation Act of 1992 specifies that wild-caught birds may be imported into the US only if they come from a country with a US Fish and Wildlife Service (FWS) approved management plan for sustainable use of the species. Before this, the US was the world's largest

**Table 1.** Life history scores for Psittacines with successful and probably successful introduced populations.

| Species | Altitude range | Migration score | Diet breadth | Ag. pest? |
|---|---|---|---|---|
| Introductions successful: | | | | |
| Sulphur-crested cockatoo (*Cacatua galerita*) | 2,400 | 0 | 4 | y |
| Rainbow lorikeet (*Trichoglossus haematodus*) | 2,440 | 0 (1) | 3 | y |
| Kuhl's lorikeet (*Vini kuhlii*) | -- | 0 | 2 | n |
| Blue lorikeet (*Vini peruviana*) | -- | 1 | 4 | y |
| Ultramarine lorikeet (*Vini ultramarina*) | 1,000 | 0 | 3 | y |
| Red Shining-parrot (*Prosopeia tabuensis*) | 1,650 | 0 | 3 | y |
| Yellow-fronted parakeet (*Cyanoramphus auriceps*) | -- | 0 | 5 | n |
| Crimson rosella (*Platycercus elegans*) | 1,900 | 0 (1) | 4 | y |
| Eastern rosella (*Platycercus eximius*) | -- | 0 | 5 | y |
| Budgerigar (*Melopsittacus undulatus*) | -- | 2 (1) | 1 | y |
| Eclectus parrot (Eclectus roratus) | 1,900 | 0 | 4 | y |
| Rose-ringed parakeet (*Psittacula krameri*) | 2,000 | 0 | 2 | y |
| Red-breasted parakeet (*Psittacula alexandri*) | 2,000 | 0 (1) | 3 | y |
| Grey-headed lovebird (*Agapornis canus*) | 1,500 | 0 | 2 | y |
| Fischer's lovebird (*Agapornis fischeri*) | 900 | 0 | 2 | n |
| Meyer's parrot (*Poicephalus meyeri*) | 2,200 | 0 (1) | 4 | y |
| Blue-crowned parakeet (*Aratinga acuticaudata*) | 2,650 | 1 | 2 | y |
| Green parakeet (*Aratinga holochlora*) | 2,300 | 0 | 2 | y |
| Mitred parakeet (*Aratinga mitrata*) | 2,400 | 1 (0) | 2 | y |
| Red-masked parakeet (*Aratinga erythrogenys*) | 2,500 | 1 | 3 | n |
| Brown-throated parakeet (*Aratinga pertinax*) | 1,200 | 2 | 3 | y |
| Black-hooded parakeet (*Nandayus nanday*) | 800 | 1 | 4 | y |
| Monk parakeet (*Myiopsitta monachus*) | 3,000 | 0 (1) | 4 | y |
| Green-rumped parrotlet (*Forpus passerinus*) | 1,800 | 2 | 4 | n |
| White-winged parakeet (*Brotogeris versicolurus*) | 2,700 | 0 | 3 | n |
| Yellow-chevroned parakeet (*Brotogeris chiriri*) | 1,560 | 1 | 3 | n |
| Hispaniolan parrot (*Amazona ventralis*) | 1,500 | 0 | 2 | y |
| Red-crowned parrot (*Amazona viridigenalis*) | 1,200 | 1 | 4 | n |
| Lilac-crowned parrot (*Amazona finschi*) | 2,000 | 2 | 2 | y |
| Yellow-headed parrot (*Amazona oratrix*) | 500 | 0 (1) | 3 | y |
| Introductions probably successful: | | | | |
| Galah (*Eolophus roseicapillus*) | 1,250 | 1 | 4 | y |
| Long-billed corella (*Cacatua tenuirostris*) | -- | 0 | 4 | y |
| Little corella (*Cacatua sanguinea*) | -- | 1 | 5 | y |
| Yellow-crested cockatoo (*Cacatua sulphurea*) | 1,200 | 0 | 4 | y |
| Blue-streaked lory (*Eos reticulata*) | -- | 0? | -- | n |
| Red-rumped parrot (*Psephotus haematonotus*) | 1,100 | 0 | 3 | n |
| Alexandrine parakeet (*Psittacula eupatria*) | 1,600 | 0 (1,2) | 4 | y |
| Plum-headed parakeet (*Psittacula cyanocephala*) | 1,500 | 0 | 4 | y |
| Rosy-faced lovebird (*Agapornis roseicollis*) | 1,500 | 0 | 2 | y |
| Yellow-collared Lovebird (*Agapornis personatus*) | 700 | 0 | 1 | n |
| Nyasa lovebird (*Agapornis lilianae*) | 1,000 | 0 | 3 | n |
| Chestnut-fronted macaw (*Ara severa*) | 1,150 | 0 (2)[4] | 2 | n |
| Yellow-crowned parrot (*Amazona ochrocephala*) | 750 | 0 (1) | 2 | y |
| Orange-winged parrot (*Amazona amazonica*) | 1,200 | 0? | 2 | y |

importer of parrots from wild populations. At least 150,000 live parrots were imported in 1990 (World Wildlife Fund 2007). Since passage of this Act, parrot imports have decreased, and captive breeding for the pet trade has increased. Since 1990, numbers imported have declined to about 17,000/year (World Wildlife Fund 2007). Mass importation, and thus mass releases and escapes, of wild-caught parrots into the US appear to be greatly reduced (Brightsmith 1999).

International restrictions in wildlife trade have similarly reduced parrot exports. From 1989-90 to 1999, numbers exported from the five main producer countries (Argentina, Guyana, Indonesia, Senegal, and Tanzania) dropped from 245,000 to 57,360 birds. Although actual origins are uncertain, 9 of the species recently sighted in Hawai`i were exported from these 5 countries. Exports of 8 of the species dropped from 88,790 to 26,290; in contrast, burrowing parakeets (*Cyanoliseus patagonus*) from Argentina entered the trade during this period and nearly 7,500 were exported (Roe et al. 2002). Despite increased regulation and quarantine requirements 2,811 parrots of 28 species were legally imported into Hawai`i in 1999 (Foster 2005, Hawai`i Department of Agriculture, unpublished data).

Future feral populations will most likely originate from small numbers of captive-bred pet parrots, rather than from large numbers of wild-caught birds. Thus, the process of establishment will likely be slow, requiring perhaps several decades, and the probability that additional parrot populations will become established should now be relatively low. However, releases of wild-caught birds being traded illegally are still possible. Cassey et al. (2004a, b) closely examined the patterns of transport, release and establishment of parrots around the world, and while the availability of individual birds for transport and release was very important, this had no obvious effect on establishment following release. Their multivariate statistical study revealed significant and independent effects of diet breadth, elevational range, and migratory habit. Sedentary, non-migratory, parrots and those with broad diets or large elevation ranges had higher establishment success. Other significant traits included lower fecundity, and longer fledgling periods.

At least 74 exotic psittacines have been reported in the wild in the US, but only 9 species are established (Table 2). Prior to 1981, 14 parrots had been introduced to the main Hawaiian islands

**Table 2.** Naturalized psittacines in the United States currently recognized by the American Ornithologists Union (AOU 1998, Banks et al. 2002), the California Bird Records Committee (2006), the Florida Ornithological Societies' Records Committee (2005), the Texas Ornithological Societies' Bird Records Committee (2006), Hawai`i Audubon Society (Pyle 2002) or the American Birding Association (ABA 2005).

| Species | AOU | California | Florida | Texas | Hawai'i | ABA |
|---|---|---|---|---|---|---|
| Budgerigar (*Melopsittacus undulatus*) | √ | | √ | | | √ |
| Rose-ringed parakeet (*Psittacula krameri*) | √ | | | | √ | |
| Mitred parakeet (*Aratinga mitrata*) | √ | | | | √ | |
| Green parakeet (*Aratinga holochlora*) | | | | √ | | √ |
| Black-hooded Parakeet (*Nandayus nenday*) | | | √ | | | |
| Monk parakeet (*Myiopsitta monachus*) | √ | | √ | √ | | √ |
| White-winged parakeet (*Brotogeris versicolurus*) | √ | | √ | | | √ |
| Yellow-chevroned Parakeet (*Brotogeris chiriri)* | | | | | | √ |
| Red-crowned parrot (*Amazona viridigenalis*) | √ | √ | | √ | √ | |

**Table 3.** Parrots introduced to Hawai`i, 1877-1981 (Moulton et al. 2001, Berger 1981, and Long 1981).

| Species | Islands | Years |
|---|---|---|
| Galah (*Eolophus roseicapillus*) | O`ahu | 1933 |
| Sulphur-crested cockatoo (*Cacatua galerita*) | O`ahu | 1933 |
| Salmon-crested cockatoo (*Cacatua moluccensis*) | O`ahu | 1981 |
| Bugerigar (*Melopsittacus undulatus*) | O`ahu | 1933 |
| Pale-headed rosella (*Platycercus adscitus*) | Maui | 1877 |
| Eclectus parrot (*Eclectus roratus*) | O`ahu | 1981 |
| Rose-ringed parakeet (*Psittacula krameri*) | Kau`ai, O`ahu, Hawai`i | 1981, 1933, 1981 |
| Peach-faced lovebird (*Agapornis roseicollis*) | O`ahu | 1973 |
| Scarlet macaw (*Ara macao*) | O`ahu | 1933 |
| Black-hooded parakeet (*Nandayus nenday*) | O`ahu, Hawai`i | 1981, 1981 |
| Monk parakeet (*Myiopsitta monachus*) | O`ahu | 1970 |
| Orange-chinned parakeet (*Brotogeris jugularis*) | O`ahu | 1933 |
| Yellow-crowned parrot (*Amazona ochrocephala*) | O`ahu | 1969 |
| Red-crowned parrot (*Amazona viridigenalis*) | O`ahu | 1971 |

(Berger 1981, Long 1981, Moulton et al. 2001, Table 3), but few are considered established (Pratt et al. 1987, Pyle 2002), at least one has been (Pyle 2002). Since 1970 (R. Pyle, unpublished data), 28 psittacines have been sighted in the wild in the state, species richness was highest on the islands of O`ahu (21) and Hawai`i (13). Currently, about 21 species regularly occur on the main islands including 11 breeding species (Table 4), and a few more species now appear to be established. Some species are being controlled and, hence, may not become established.

## ESTABLISHMENT PATTERNS

Generally, only a small proportion of exotic birds introduced to new locations have established wild populations, and have created negative impacts in the new environment (Lockwood 1999). Overall, less than 3% of all avian species have established nonindigenous populations somewhere in the world (Lockwood 1999) and 36% of alien birds introduced to Hawai'i have established breeding populations (Loope et al. 2001). Overall, parrots had even higher rates of establishment: 70% of 54 species intentionally released established naturalized populations (Cassey et al. 2004b). For long-lived birds like parrots, it can be hard to know if they are truly established, or are simply living out a long life span in a new location.

The highest diversity and abundance of nonindigenous parrots in the US occurs primarily in the subtropical areas of Florida, California and Texas (Pranty and Garrett 2003). The proportion of introduced and naturalized species is greater in urban/suburban areas than in rural areas and parrots fit this pattern (Spreyer and Bucher 1998, Lamont 2002, Butler 2003, Domenech et al. 2003, Eguchi and Amano 2004). Additionally, parrots usually exploit habitats dominated by exotic flora (Lamont 2002). In a few cases, however, a parrot species will colonize important agricultural areas (Domenech et al. 2003).

The occurrence of feral parrots non-urban/suburban areas may be due to a relatively large pool of potential escapees. Compared to rural areas, densities of pet parrots, like people, are likely much higher in urbanized areas; both density and diversity of feral parrots is especially high near ports of entry (e.g., Miami, Honolulu). Like southern California and southeastern Florida, Hawai`i has a mild climate, urban areas extensively landscaped with exotic vegetation, and major ports of entry. This, along with a lack of natural predators and abundant sources of invasive exotic

**Table 4.** Parrots possibly breeding and reported from the wild in Hawai`i since 1990. Species in bold typeface were identified as agricultural pest species, or as feeding on crops, orchards etc., in their native ranges by del Hoyo et al. (1997).

| Species | Islands |
|---|---|
| 11 breeding species: | |
| **Tanimbar cockatoo** (*Cacatua goffini*) | Maui |
| **Sulphur-crested cockatoo** (*Cacatua galerita*) | Maui |
| **Rose-ringed parakeet** (*Psittacula krameri*) | Hawai`i, Kaua`i, Maui, O`ahu |
| **Peach-faced lovebird** (*Agapornis roseicollis*) | Maui |
| Blue and yellow macaw (*Ara ararauna*) | Maui |
| Military macaw (*Ara militaris*) | Maui |
| **Scarlet-fronted parakeet** (*Aratinga wagleri*) | Hawai`i |
| **Mitred parakeet** (*Aratinga mitrata* ) | Maui |
| Red-masked parakeet (*Aratinga erythrogenys*) | O`ahu |
| **Burrowing parakeet** (*Cyanoliseus patagonus*) | Hawai`i |
| Red-crowned parrot (*Amazona viridigenalis*) | O`ahu |
| 13 species sighted since 1990: | |
| Salmon-crested cockatoo (*Cacatua moluccensis*) | Hawai`i, Maui, O`ahu |
| **Cockatiel** (*Nymphicus hollandicus*) | All |
| Black lory (*Chalcopsitta atra*) | Hawai`i |
| **Budgerigar** (*Melopsittacus undulatus*) | Maui, O`ahu |
| **Eclectus parrot** (*Eclectus roratus*) | Hawai`i, Kaua`i, O`ahu |
| **Alexandrine parakeet** (*Psittacula eupatria*) | Maui |
| **African grey parrot** (*Psittacus erithacus*) | Hawai`i |
| **Senegal parrot** (*Poicephalus senegalus*) | Hawai`i, Kaua`i, O`ahu |
| **Brown parrot** (*Poicephalus meyeri*) | Kaua`i |
| **Blue-crowned parakeet** (*Aratinga acuticaudata*) | O`ahu |
| **Black-hooded parakeet** (*Nandayus nenday*) | Hawai`i |
| **Yellow-crowned parrot** (*Amazona ochrocephala*) | O`ahu |
| Blue-fronted parrot (*Amazona aestiva*) | Maui, O`ahu |

food plants, likely increases the probability that introduced parrots will establish naturalized populations of psittacines. Three of the 9 species established on the mainland US (Table 2) are present and established in Hawai`i and if introduced, the other 6 presumably have the capacity to become established.

## METHODS

We compiled and tabulated life history information (T. Pratt and J. Foster, unpublished data, Forshaw 1977, del Hoyo et al. 1997, Juniper and Parr 1998). Introduction histories were gleaned from Garret et al. (1997), Simberloff et al. (1997), Lever (1987), Long (1981), and reviews of official state lists of bird status and occurrence for California, Florida and Texas. Using these data we calculated scores for three of the traits shown by Cassey et al. (2004b) to be correlated with successful establishment of introduced psittacines: extent of altitudinal range, diet breadth, and degree of migration. The scores used in their analyses were not available to us, and we calculated them based on the descriptions in Cassey et al. (2004b). Altitude range was the difference between the normal upper and lower altitudinal range limits of a species in its natural range. Diet breadth reflected the composition of each species diet scored as presence or absence of five different food types: fruit/berry, seed/grain, vegetative material, animal

material or nectar/flower. Each diet category was scored as 0 or 1 and summed (range 1 to 5). Cassey et al. (2004b) scored diets based on the first four of these categories only. Degree of migration was scored as: (0) for resident species with local movements only, (1) for nomadic species with irruptive seasonal movements, and (2) for species with regular altitudinal or geographical migrations. Unlike the previous two variables, migration score was inversely related to establishment success (Cassey et al. 2004b). We scored migration habit for a limited number of parrots which scored highly for altitudinal range and diet breadth, or which we judged potentially important based on their likelihood of establishment success, presence in Hawai'i, etc. For a similarly limited number of species we also noted if they were identified as agricultural pests, or reportedly fed on crops or orchards in their native ranges (del Hoyo et al. 1997).

In an effort to identify psittacines that could become established, and perhaps invasive, we searched data from the National Audubon Society's (NAS) annual Christmas Bird Counts (CBC) and looked for parrots that were both widespread and abundant. Our figures were created from the data accessible from the Audubon website: www.audubon.org/bird/cbc. To examine relative distribution among species we used the number of count circles where a species was reported in each count year for each state. For abundance we used the sum of all individuals reported in each count year for each state. Because we were most interested in total numbers of birds reported, rather than in statistical trend analyses, we have presented these data uncorrected for survey effort, and have made no inferences to larger geographical areas outside of the CBC circles. However, we note that there are both advantages and limitations to using CBC data to examine status of exotic birds (Pranty 2002, Butler 2005).

To identify broadly distributed psittacines with large populations, we examined counts from seven recent CBC seasons (winters of 1999-2000 through 2005-2006) from the three states with the highest diversity of exotic parrots: California, Florida and Texas. As a relative index to the extent of distribution within each state we used the maximum number of count circles that reported each species during this time period. The maximum of the annual sum of all individuals reported was used to index each species abundance. To facilitate visual comparisons among species these two index values were used as x,y coordinates to plot distribution on the horizontal axis and abundance on the vertical axis.

We used similar metrics to portray recent changes in distribution and abundance with indices based on changes in numbers of CBC count circles and numbers of birds counted for each of the three states. For each species, changes in distribution were indexed as:

No. of count circles reported in 2006 ÷
No. of count circles reported in 2000

Changes in abundance were similarly indexed as:
Total no. of individuals reported in 2006
÷ Total no. reported in 2000

Our goal was to highlight species that had clearly shown the ability become both widespread and abundant. Our measures of distribution and abundance are ordinal indexes only, not statistical estimates. For inferences comparing abundances of different species and changes over time, statistical analyses were limited to nonparametric, rank order methods using SAS® version 9.1 (SAS Institute, Cary, NC). Spearman rank correlation coefficients ($R_s$) were used to analyze long-term (>10 years) trends in abundance and distribution of exotic parrot species on CBC circles within California and Florida; data from Texas were too sparse to analyze. To identify species with significant trends over time, $R_s$ was calculated by year with number of individual birds reported; and for year with number of CBC circles where a species was reported. $R_s$ values, and significance levels, reflected how closely the rank order of each variable corresponded with year. Inferences here were limited to concluding whether or not trends over time were statistically significant at the 10% level; we did not calculate trend lines or estimate rates of population growth.

## RESULTS AND DISCUSSION

Psittacines with successful, or probably successful, introduced populations somewhere in the world are listed in Table 1. Most were from the subfamily Psittacinae, but five cacatuids, and four loriinids were also included. An established species becomes invasive when both distribution and abundance increase, and data from CBC circles (NAS 2002) demonstrated that monk parakeets, from South America, have increased in both

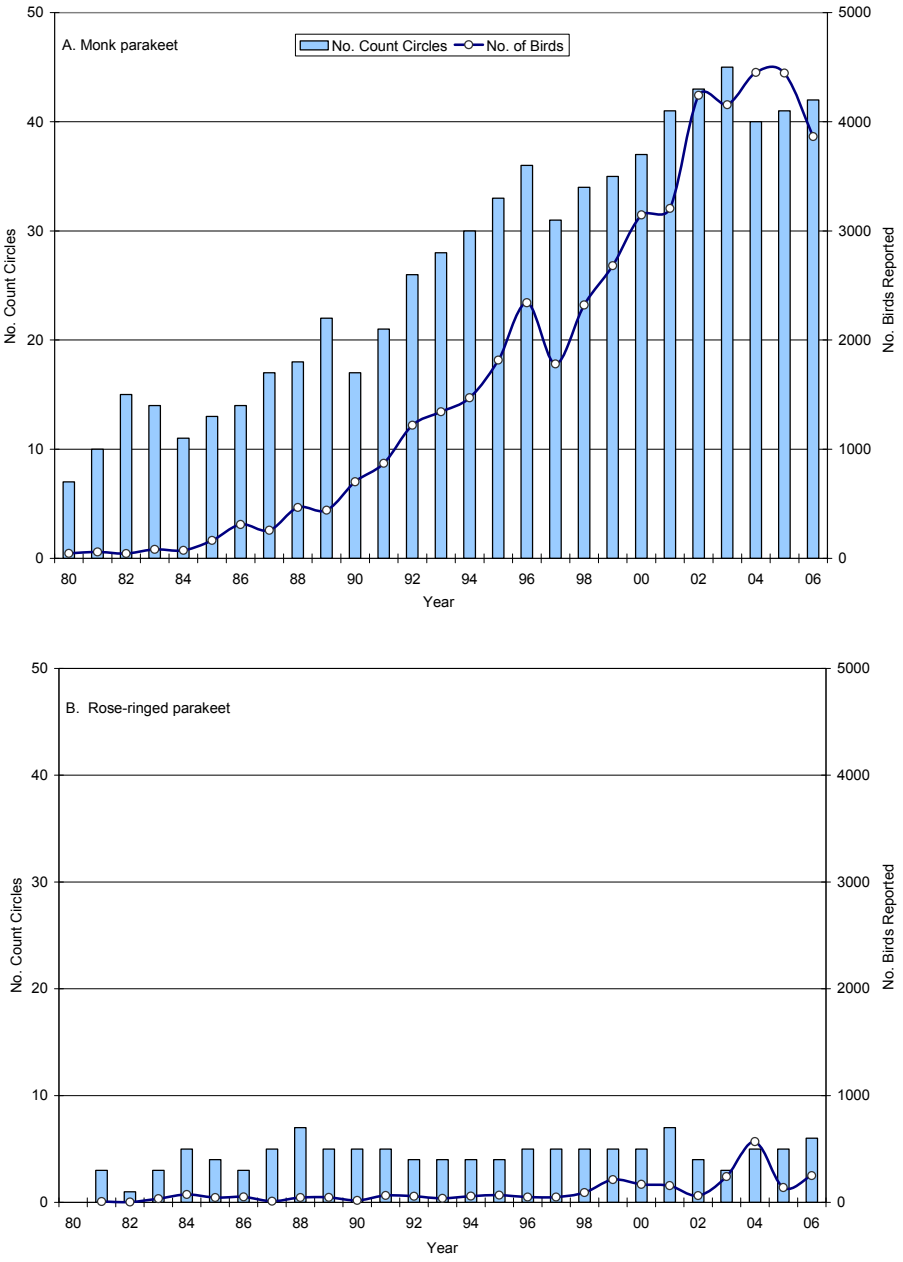


**Figure 1.** Trends in distribution and abundance of monk parakeets and rose-ringed parakeets from CBC circles within the US, 1980-2006.

numbers and distribution in North America (Figure 1a). Originating from multiple releases in the 1960s, they have recently bred in 11 states and Puerto Rico (Spreyer and Butcher 1998). At the same time, rose-ringed parakeet populations, introduced to the US in the mid-1960s to 1970s, have remained much more limited (Figure 1b) and were largely restricted to southern California, south Florida and Kaua'i. Patterns of population growth for established psittacines in Florida varied (Figures 2, 3) and included a period of slow growth followed by rapid expansion in both range and population size for monk (*Myiopsitta monachus*) and black-hooded parakeets (*Nandayus nenday*); both are now established members of the local avifauna. The initial high growth rate and spread of the budgerigar population, fueled by large scale releases of captive-bred birds, was followed by a sudden collapse (Figure 2b). Such crashes are common among naturalized species (Simberloff and Gibbons 2003) and exotic birds whose populations have exploded may not remain abundant. Examples from Hawai`i include the common myna (*Acridotheres tristis*), red-billed

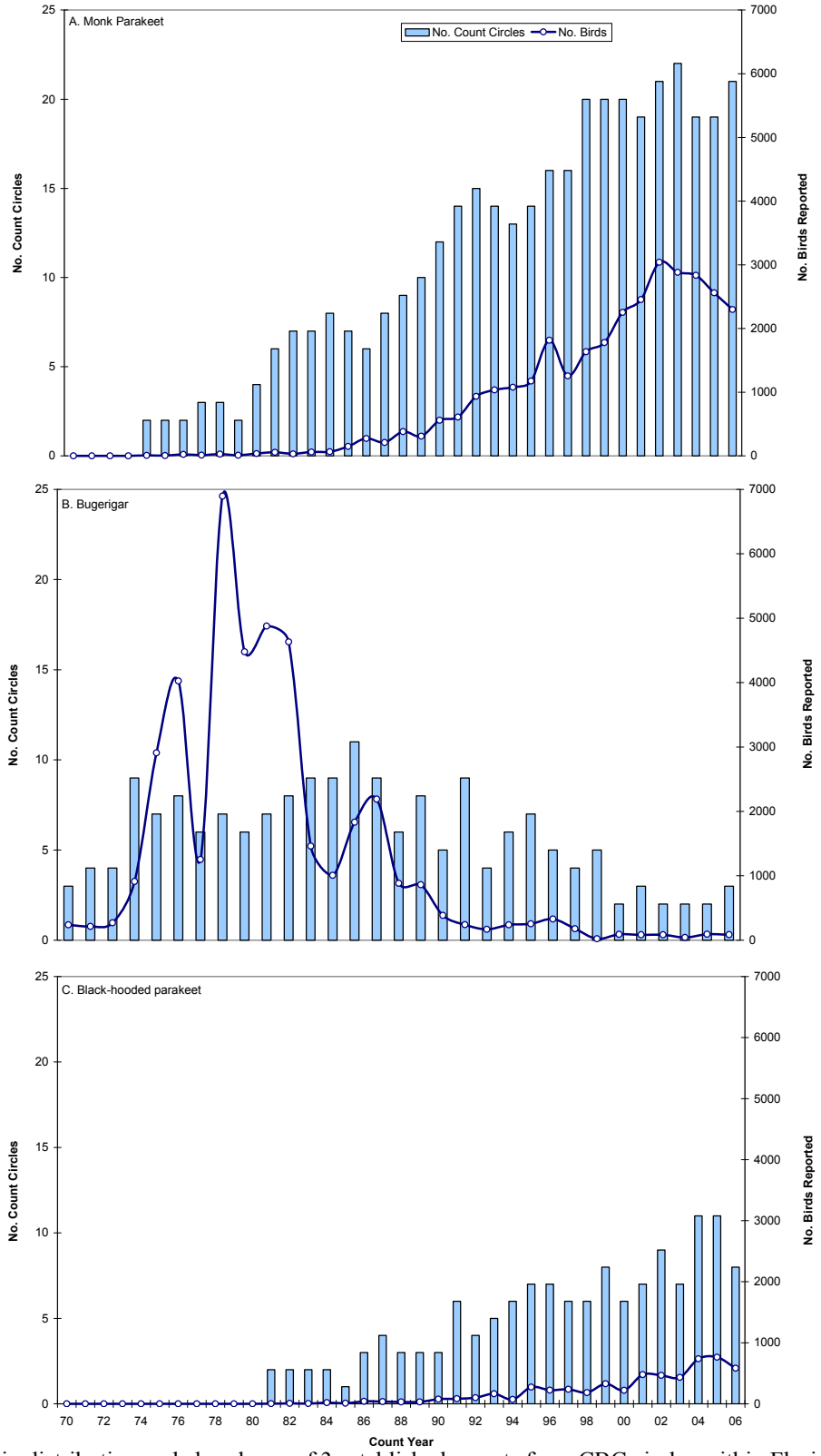


**Figure 2.** Trends in distribution and abundance of 3 established parrots from CBC circles within Florida, 1970-2006. Monk parakeets are invasive pests but may be declining (A); bugerigars range has contracted and numbers have plummeted (B); black-hooded parakeets are recently established (C).

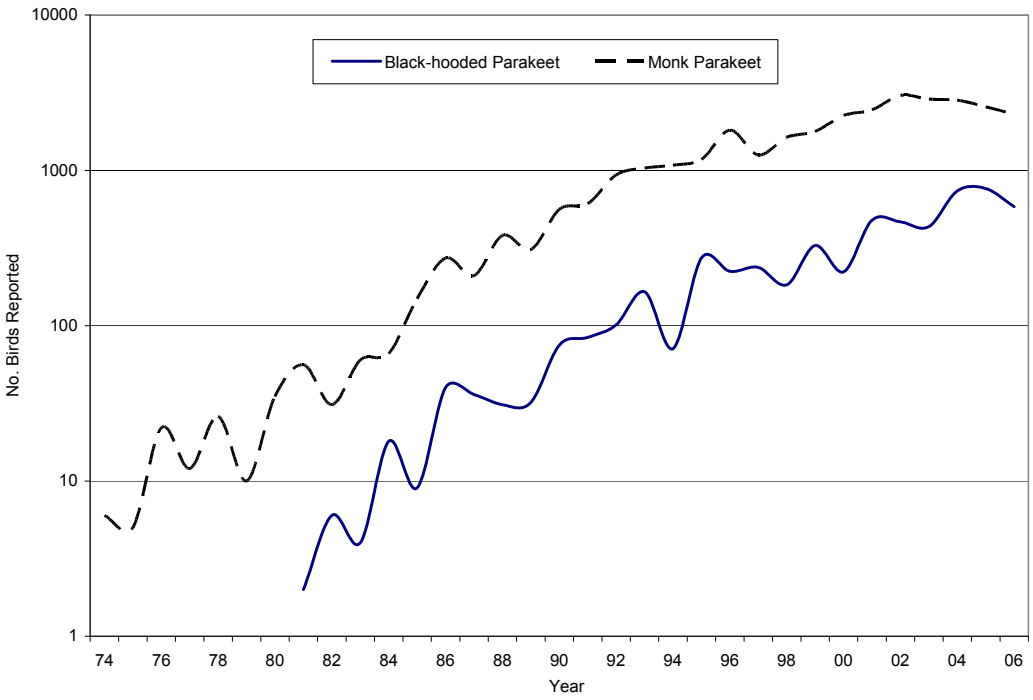


**Figure 3.** Trends in numbers of black hooded parakeets (solid line) and monk parakeets (dashed line) from CBC circles within Florida, 1974-2006.

leiothrix (*Leiothrix lutea*), and the varied tit (*Parus varius*, Foster 2005).

There were sufficient data to examine long-term (11 to 33 years) trends in distribution and abundance for 15 species in California and Florida (Table 5). Mitred (*Aratinga mitrata*), black-hooded and yellow-chevroned parakeets (*Brotogeris chiriri*) each had significant ($P \leq 0.10$) positive correlations over time for both numbers of individual birds reported and numbers of CBC circles within both states. Hence, both numbers and distribution increased over time. Conversely, budgerigars (*Melopsittacus undulatus*), yellow-headed parrots (*Amazona oratrix*), and red-crowned parrots (*Amazona viridigenalis*) showed significant negative correlations, indicating declines over time in Florida.

Data from CBC circles within California and Texas were adequate to portray the relative status of 16 species (Figures 4, 5), and 26 species in Florida (Figures 6, 7). These graphic summaries provided a snapshot of the relative status of different species on a state-by-state basis; widespread and abundant parrots appeared in the upper right, while smaller relatively localized populations appeared closer to the origin (Figures 4, 6). Populations which may have been relatively small and limited geographically, but which recently showed rapid increases in distribution and abundance appeared further to the right and above those with slowly expanding populations (Figures 5, 7). Numbers of three *Brotogeris* parakeets counted on CBC circles within California and Florida peaked at 200-300 (Figures 8, 9). Similarly for five species of *Aratinga* parakeets, numbers peaked at <100 to >300 (Figures 8, 10).

Rose-ringed parakeets (*Psittacula krameri*) were first recorded from CBC circles in Florida in 1974 (Figure 11), but were not reported from California until 10 years later with numbers relatively low for many years. Similarly, black-hooded parakeets were first recorded in Florida in 1981, about 10 years before they were reported from California, and were well established in south Florida by the early 2000s. Trends for five *Amazona* species are shown in Figures 12-14. Numbers of three *Amazona* species counted on CBC circles within California and Florida peaked at less than 50 birds, numbers of two others were higher (Figures 12-14).

Pranty (2001, 2002) used CBC data to graph population changes over time for 10 species of exotics, including three psittacines. Brightsmith (1999) used data from specific CBCs in south Florida and Los Angeles to help describe changes

**Table 5.** Long-term (>10 years) trends in abundance and distribution of exotic parrot species on CBC circles within California and Florida, 1970 to 2006. Values are Spearman rank correlation coefficients ($R_s$) for year with number of individual birds reported; and for year with number of CBC circles where a species was reported. Species with significantly increasing and expanding populations in both states are in bold typeface.

| | California | | | Florida | | |
|---|---|---|---|---|---|---|
| **Species** | **Years (no. yrs)** | **$R_s$ (abundance)** | **$R_s$ (CBC circles)** | **Years (no. yrs)** | **$R_s$ (abundance)** | **$R_s$ (CBC circles)** |
| Budgerigar | --- | --- | --- | 1970-2006 (30) | -0.55 *** | -0.22 |
| Rose-ringed parakeet | 1984-2006 (23) | 0.84 *** | 0.81 *** | 1974-2006 (33) | 0.22 | 0.32 |
| Blue-crowned parakeet | --- | --- | --- | 1989-2006 (18) | 0.61 *** | 0.42 * |
| Green parakeet | --- | --- | --- | 1984-2006 (23) | 0.39 * | 0.30 |
| **Mitred parakeet** | 1991-2006 (16) | 0.70 *** | 0.60 ** | 1989-2006 (18) | 0.61 *** | 0.45 * |
| **Red-masked parakeet** | 1994-2006 (13) | 0.76 *** | 0.73 *** | 1989-2006 (18) | 0.60 *** | 0.41 * |
| White-eyed parakeet | --- | --- | --- | 1989-2006 (18) | 0.58 ** | 0.45 * |
| Black-hooded parakeet | 1990-2006 (17) | 0.73 *** | 0.30 | 1981-2006 (26) | 0.97 *** | 0.94 *** |
| Monk parakeet | --- | --- | --- | 1974-2006 (33) | 0.99*** | 0.97 *** |
| **Yellow-chevroned parakeet** | 1996-2006 (11) | 0.67 ** | 0.90 *** | 1995-2006 (12) | 0.79 *** | 0.64 ** |
| Red-crowned parrot | 1976-2006 (31) | 0.86 *** | 0.86 *** | 1975-2006 (32) | -0.16 | -0.33 * |
| Lilac-crowned parrot | 1979-2006 (28) | 0.38 ** | 0.47 ** | --- | --- | --- |
| Blue-fronted parrot | --- | --- | --- | 1995-2006 (12) | 0.69 ** | 0.07 |
| Yellow-crowned parrot | 1975-2006 (32) | -0.25 | -0.05 | 1978-2006 (29) | -0.67 *** | -0.45 ** |
| Orange-winged parrot | --- | --- | --- | 1989-2006 (18) | 0.30 | 0.58 ** |

* = $P \leq 0.10$, ** = $P \leq 0.05$, *** = $P \leq 0.01$

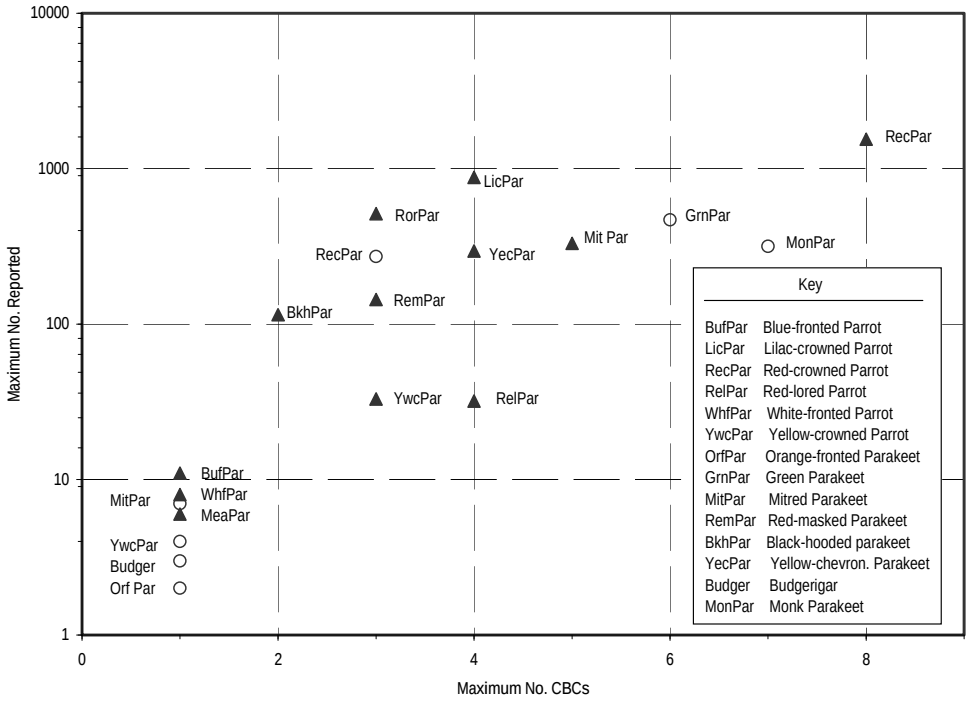


**Figure 4.** Distribution and abundance of 12 exotic parrots from CBC circles within California (solid triangles) and 7 species within Texas (open circles), 2000-06.

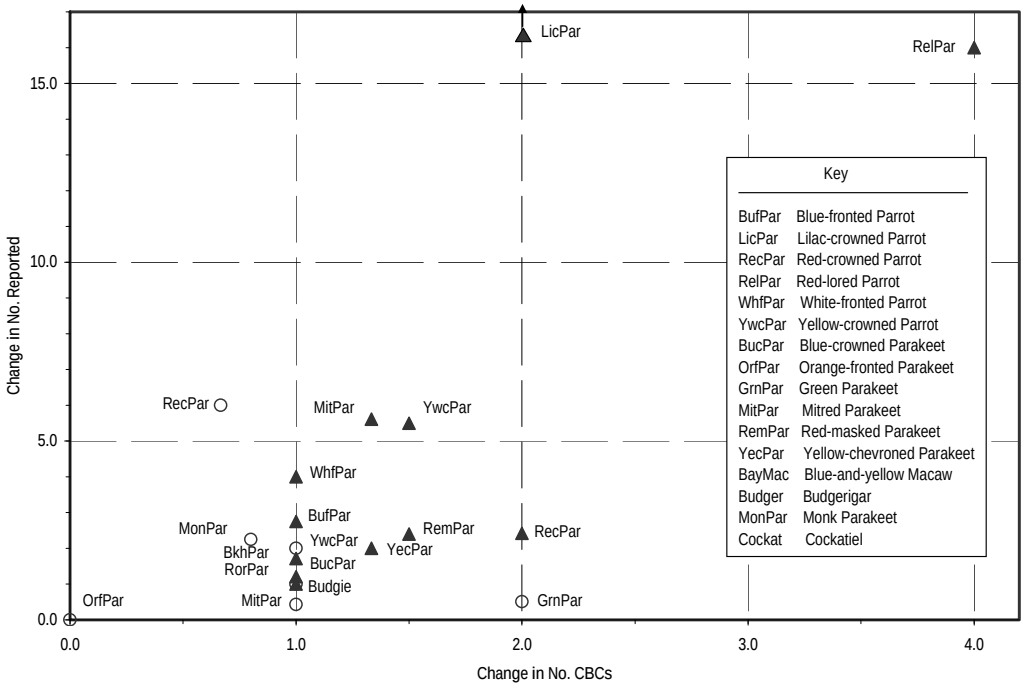


**Figure 5.** Changes in abundance and distribution of 16 exotic parrots from CBC circles within California (solid triangles) and 6 species in Texas (open circles), 2000-06.

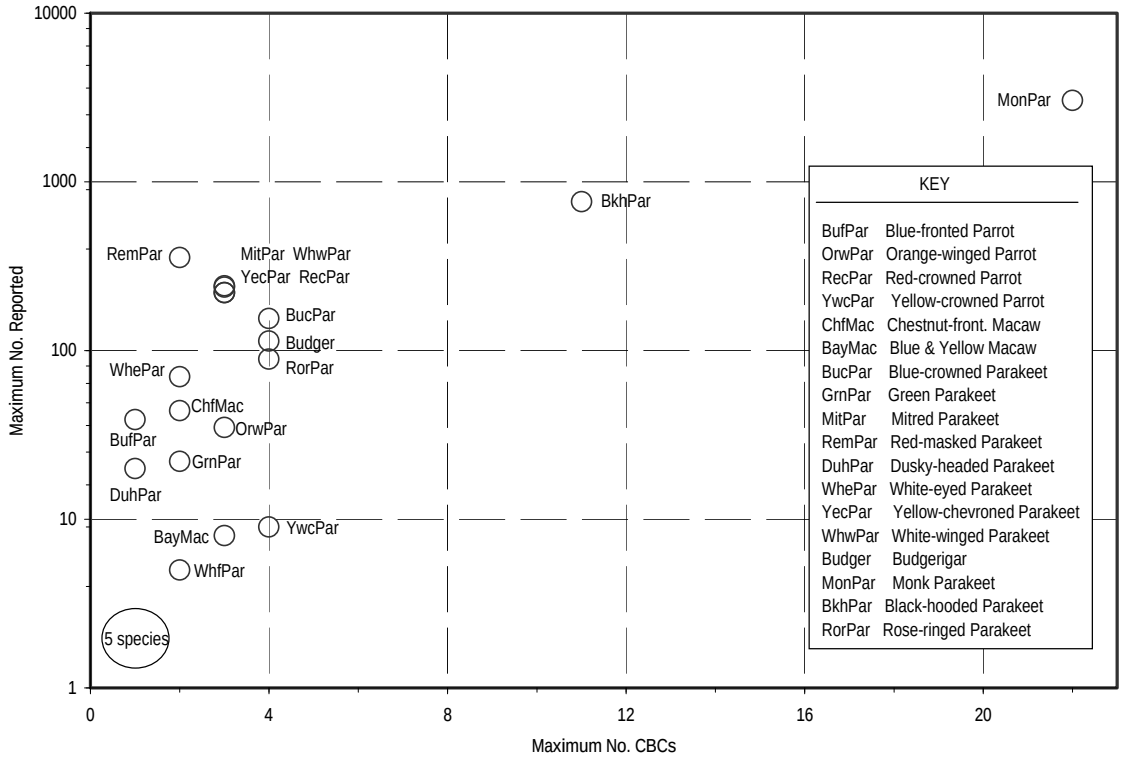


**Figure 6.** Distribution and abundance of 19 exotic parrots reported from CBC circles within Florida, 2000-06. Five additional species were reported from 1 count circle with <5 individuals: orange-fronted parakeet, red-lored parrot, lilac-crowned parrot, crimson-fronted parakeet, and cockatiel.

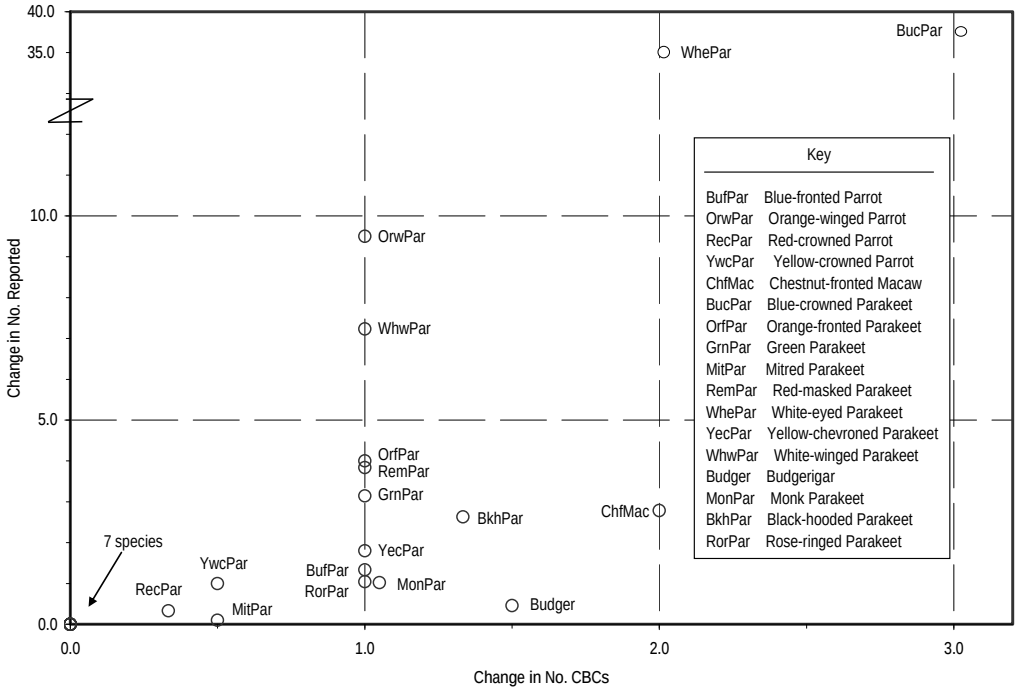


**Figure 7.** Changes in distribution and abundance of 18 exotic parrots from CBC circles within Florida, 2000-06. Seven additional species showed no net changes during this period: blue and yellow macaw, crimson-fronted parakeet, dusky-headed parakeet, lilac-crowned parrot, red-lored parrot, white-fronted parrot, and cockatiel.

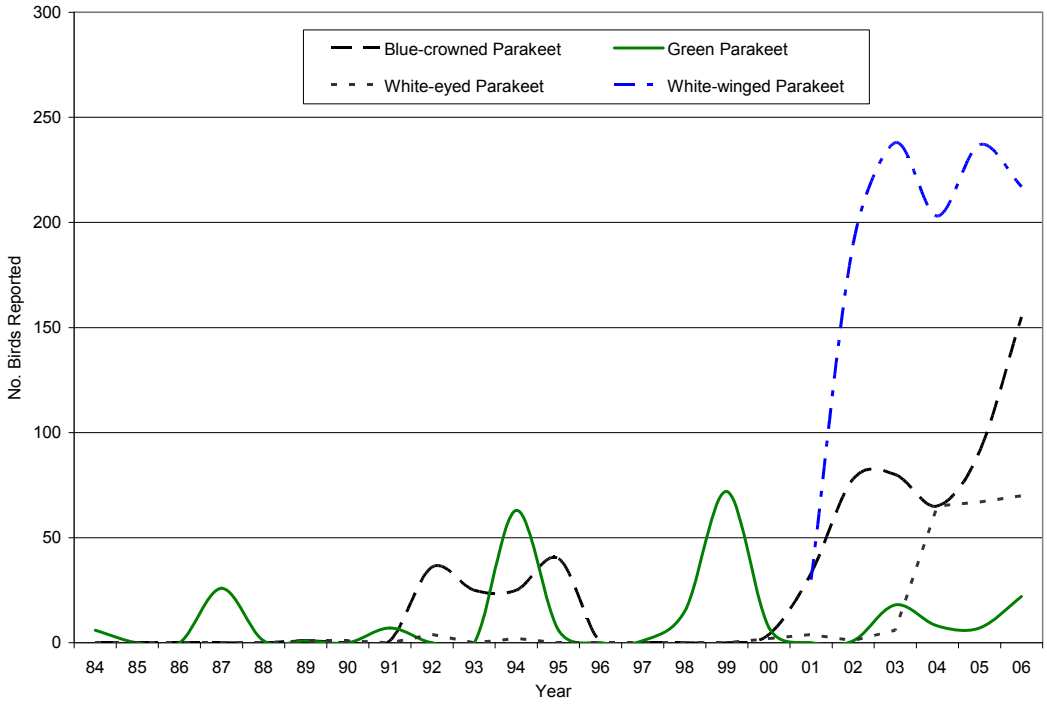


**Figure 8.** Trends in numbers of blue-crowned parakeets, green parakeets, white-eyed parakeets and white-winged parakeets from CBC circles within Florida, 1984-2006.

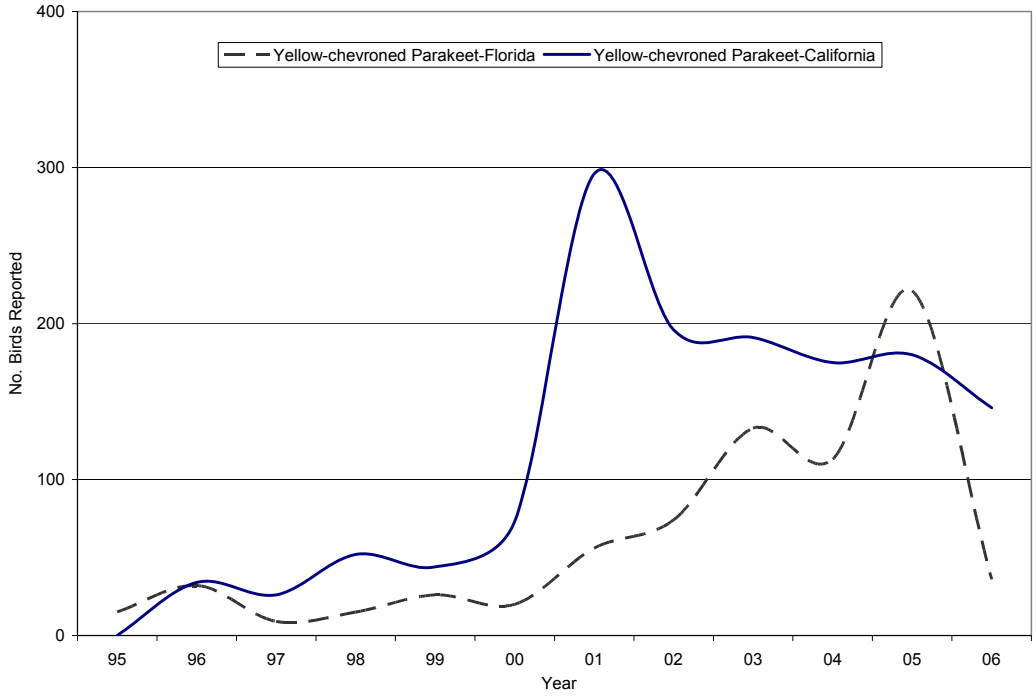


**Figure 9.** Trends in numbers of yellow-chevroned parakeets from CBC circles within California (solid line) and Florida (dashed line), 1995-2006.

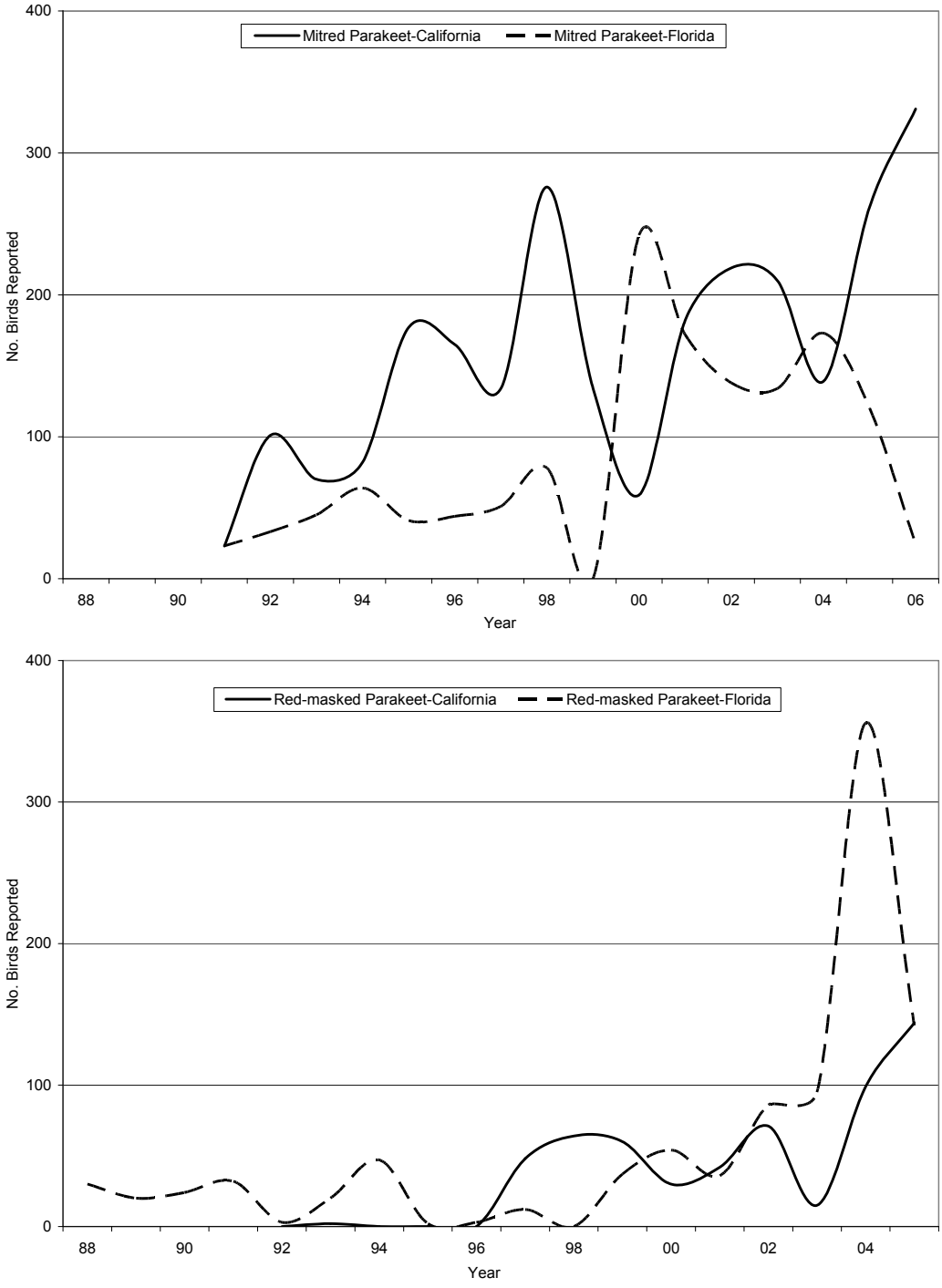


**Figure 10.** Trends in numbers of mitred parakeets and red-masked parakeets from CBC circles within California (solid line) and Florida (dashed line), 1988-2006.

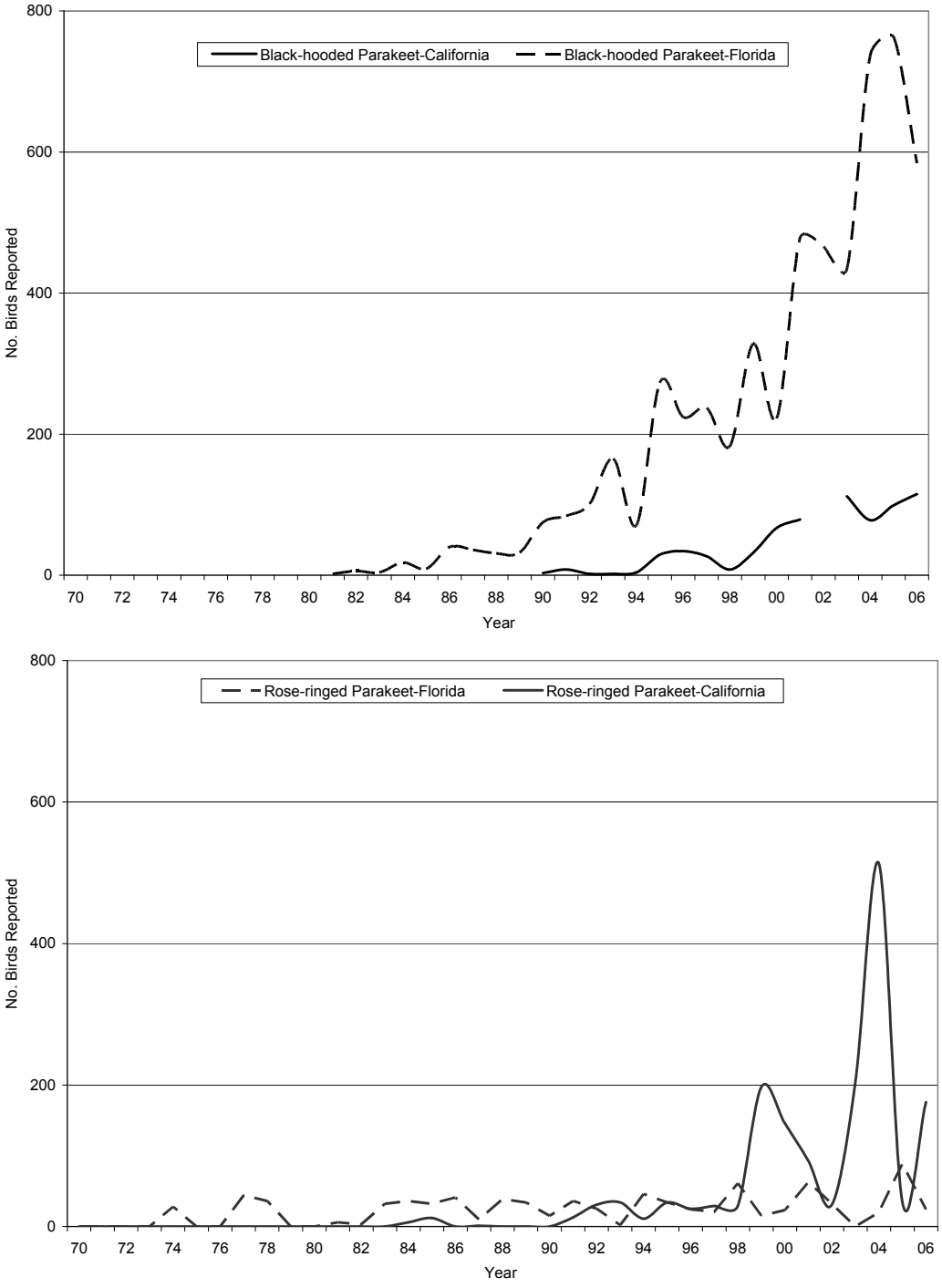


**Figure 11.** Trends in numbers of black-hooded parakeets and rose-ringed parakeets from CBC circles within California (solid line) and Florida (dashed line), 1970-2006.

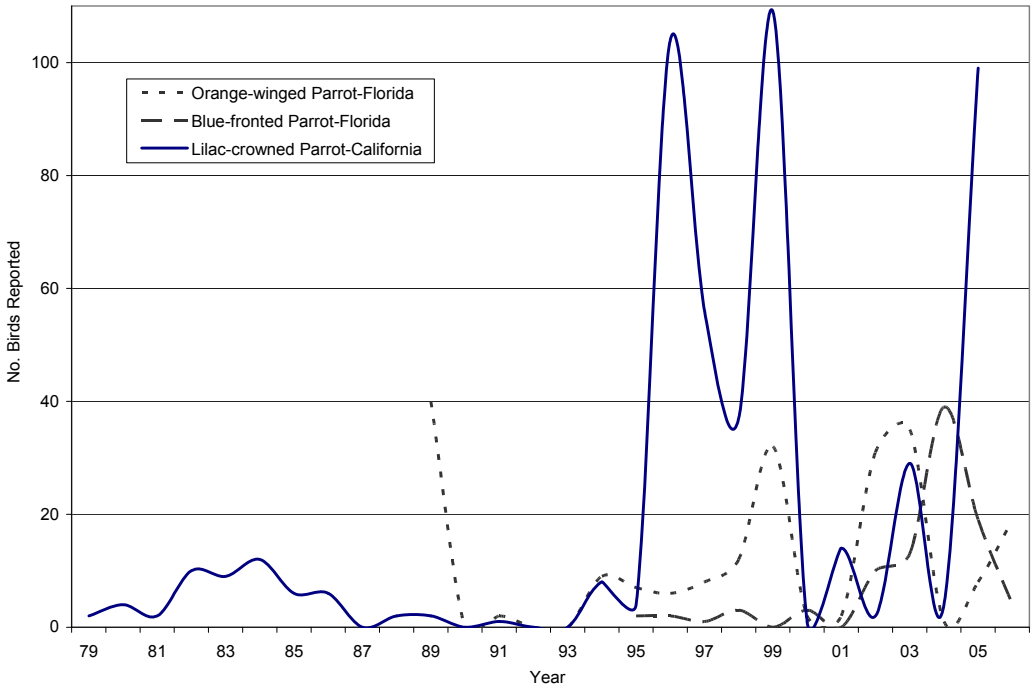


**Figure 12.** Trends in numbers of orange-winged parrots, blue-fronted parrots and lilac-crowned parrots from CBC circles within Florida and California, 1979-2005.

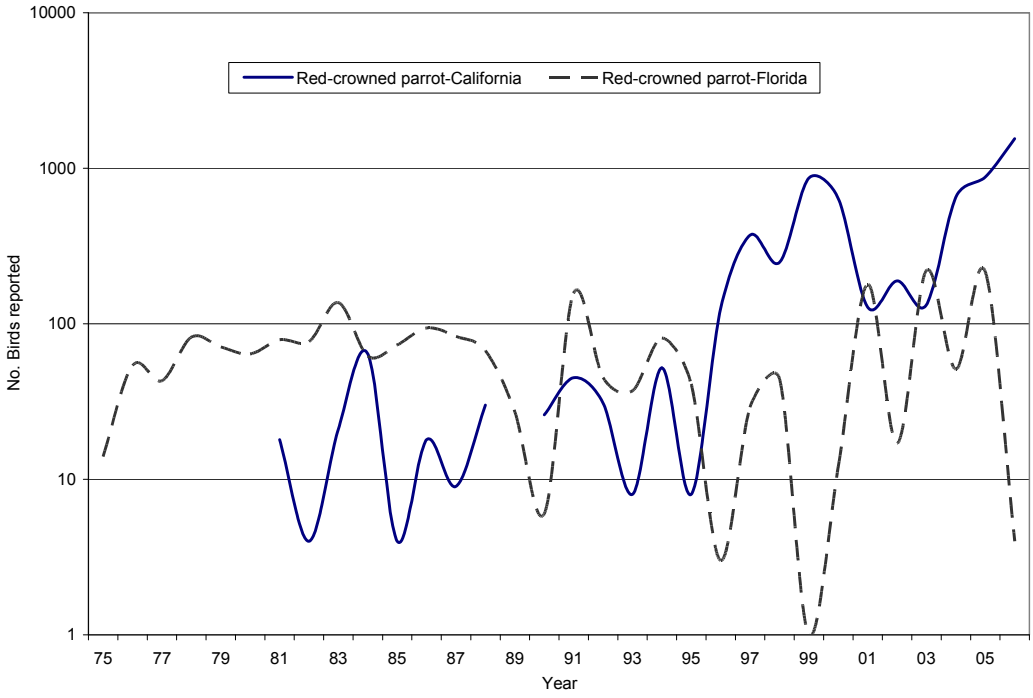


**Figure 13.** Trends in numbers of red-crowned parrots from CBC circles within California (solid line) and Florida (dashed line), 1988-2006.

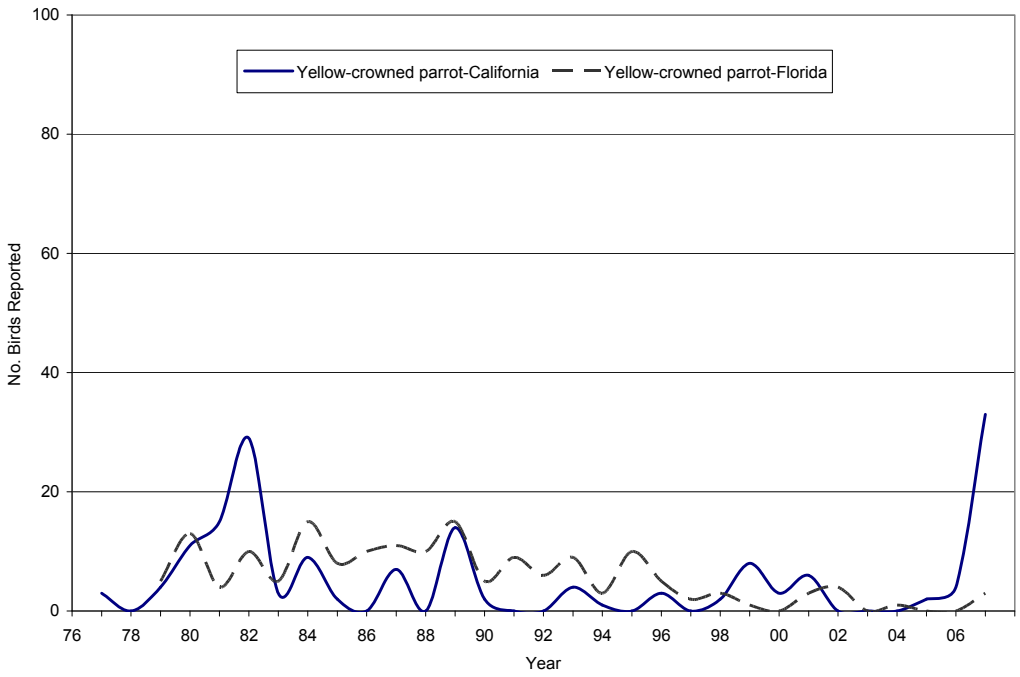


**Figure 14.** Trends in numbers of yellow-crowned parrots from CBC circles within California (solid line) and Florida (dashed line), 1976-2006.

in local *Brotogeris* parakeet populations. In his review of feral parrot populations, Butler (2005) described the status of several species on CBC circles within the US and identified five psittacines with significantly increasing populations: mitred, blue-crowned (*Aratinga acuticaudata*), and black-hooded parakeets, blue-fronted parrot (*Amazona aestiva*) , and chestnut-fronted macaw (*Ara severa*). Our results supported the idea that the three parakeets he identified have expanded in both numbers and distribution, and that the blue-fronted parrot population has increased (Table 5), but we could not confirm this for the chestnut-fronted macaw.

Population trends of monk parakeets have been analyzed with CBC data (Van Bael and Pruett-Jones 1996, Avery et al. 2002, Pruett-Jones et al. 2007) to show that the US and Florida populations of monk parakeets were increasing exponentially and doubling every six to seven years. Similar population expansions have been observed in Europe, where the species is also established (Sol et al. 1997). Plots of recent CBC data suggested that they may beginning to decline (Figure 1, 2) but long-term trends in abundance and distribution in Florida (Table 5) and across the US were positive ($R_s > 0.92$, $P < 0.0001$).

Monk parakeets are the best example of an invasive pest parrot in North America, but while distribution has increased over time (Figure 1) it remains limited. They have been reported from no more than 2.8% of all CBC circles across North America, but at the statewide scale they have been reported from up to 35% of the circles in Florida. To put these numbers in perspective, in recent decades, the invasive European starling has occurred on up to 96% of CBC circles across North America.

In contrast to the monk parakeet, the budgerigar population, which was deliberately established after repeated releases of up to 3,000 birds along the central Gulf Coast of Florida, did not become invasive (Figure 2). In the late-1970s, total numbers in the wild peaked at >20,000 birds. The population was concentrated in five counties along the Gulf Coast, but included birds widely scattered across 31 of Florida's 67 counties (Pranty 2001).

Budgerigars then declined dramatically in both abundance and distribution during the 1980s and 1990s, and recently numbered <200 birds in just two counties (Wenner and Hirth 1984, Pranty 2001, NAS 2002, Florida Fish and Wildlife Conservation Commission 2003). Pranty (2001) and Butler (2005) reviewed the potential causes for this population crash, but data are sparse and no firm conclusion has been presented. A breeding population on Tresco Island in the United Kingdom (UK) followed a similar track: in less than 10 years,

10 pairs increased to 100 birds then crashed and vanished after the resident who fed the birds moved away (Butler 2005). Rank correlation analyses for budgerigars reflected the dramatic decline in numbers from CBC circles within Florida, but the decline in distribution (Figure 2) was not significant (Table 5). An intermediate example (Figure 2c) is the recently established black-hooded parakeet population whose limited range is expanding in Florida (NAS 2002, Pranty and Lovell 2004). They are not currently considered invasive, but their numbers appear to be on the same trajectory as the monk parakeet (Figure 3).

Our calculations and graphs were designed to compare the relative abundance and distribution status of exotic populations of parrots in order to identify species that have increased rapidly in numbers and distribution. Our comparisons were relative and restricted to psittacines reported from CBC circles and the distribution of most species was relatively limited. In California, none occurred on more than 8 count circles. For Texas, the maximum number of CBCs was 7 seven circles (Figure 4). Similarly for Florida, only two species (monk and black-hooded parakeets) were reported from more than 4 CBCs (Figure 6).

The graphic summaries of recent (1999-2006) data from CBC circles within Florida, California, and Texas highlighted the following species as relatively widespread and abundant: monk parakeet, black-hooded parakeet, red-crowned parrot, green parakeet (*Aratinga holochlora*) , and mitred parakeet (Figures 4, 6). These 5 species were previously recognized as established by experts in the US (Table 2). The most rapidly expanding and increasing species in these years were the blue-crowned parakeet, white-eyed parakeet (*Aratinga leucophthalmus*), lilac-crowned parrot (*Amazona finschi*) and red-lored parrot (*Amazona autumnalis lilcana*; Figures 5, 7) which may be in the process of establishing naturalized populations. In addition to these, longer-term trends in numbers indicate that the yellow-chevroned and white-winged parakeet (*Brotogeris versicolurus*) are capable of rapid, if not sustained, population increases (Figures 8, 9).

As predicted by an exponential population growth curve, many exotic vertebrate populations have shown lag phases in population growth after introduction (Mack et al. 2000). After initial releases, introduced populations may first grow slowly as they build momentum and then suddenly irrupt. Following releases in Hawai`i, several currently naturalized birds were not found breeding or even sighted for many years (e.g., barn owls (*Tyto alba*), white-rumped shama (*Copsychus malabaricus*), and Guam swiftlets (*Aerodramus bartschi*; Foster 2005). Populations of the common myna and red-billed leiothrix both experienced a slow building period followed by rapid growth in Hawai`i (Foster 2005). CBC data reflected a similar pattern for several introduced parrot populations as well. Examples from Florida included monk parakeets (Figures 2, 3) and white-eyed parakeets (Figure 8) whose numbers built slowly for >10 years. In comparison, red-masked parakeet counts remained low for about 15 years (Figure 10). Black-hooded parakeets were recently accepted as an established part of Florida's avifauna following a lag of about 15 years (Figures 2, 3, 11). Counts of several *Amazona* spp. fluctuated greatly but have remained low for 10-20 years (Figures 12, 13). Similarly, Maui's mitred parakeet population, which was founded by a single pair, took 15 years to reach 200 (Runde and Pitt 2006). The lag periods for south Florida's yellow-chevroned and white-winged parakeets appeared short at about 5 years (Figures 8, 9), but both populations were founded by large-scale escapes of wild birds in the pet trade (Brightsmith 1999).

Lag periods for rose-ringed parakeets appear to be on the scale of decades. Numbers on California CBCs remained <200 for >20 years and still appeared low after 30 years in Florida (Figure 11). Established populations of rose-ringed parakeets in the UK appeared to grow slowly from 1969-1996, but have increased exponentially since then. Annual increases have recently been estimated at 15 to 30%, but range expansion at 300-400 m/yr has been relatively slow (Butler 2003). Similar growth rates were noted in the Netherlands, where the population has increased at a rate of 22.5% per year since 1994 (Keiji 2001). For long-lived parrots with low reproductive rates, this phenomenon of long lag periods preceding exponential population growth makes it especially difficult to determine if feral populations will become established or invasive and argues for timely control of incipient populations even though they may appear stagnant for 20-30 years.

## POTENTIAL IMPACTS OF EXOTIC PARROTS

Established populations of exotic parrots may pose problems to Hawai`i's natural systems as well as human health and safety, and agriculture. Since there are no native psittacines, emerging parrot populations may present novel threats to Hawai`i's ecology in ways that previous bird introductions have not. Although most psittacines are seed predators and are not generally recognized as seed dispersers, they do feed on many exotic invasive plants and there is concern that they may disperse viable seeds and over large areas. For example, mitred parakeets are known to feed on *Miconia calvescens* berries in their home range and captive feeding trials on Maui indicated that they can pass viable *Miconia* seeds (Gassmann-Duval 2002). and thus may currently be a factor in the long distance dispersal of invasive *Miconia* into native forests and other areas where much effort has been put into eradication. However, most parrots are seed predators feeding on immature seeds, thus the extent to which exotic parrots in general may disperse alien plants is unclear (Loope et al. 2001; J. Gilardi, personal communication).

As seed predators, parrots may inhibit reproduction of native tree species. Important foods for exotic parrots in Los Angeles included several palms (*Araceae* spp.; Garrett et al. 1997) and introduced sulfur-crested cockatoos (*Cacatua galerita*) reportedly fed on hearts of palm and devastated large stands of two endemic palms found only in Palau's rock islands (Engbring 1992, Loope et al. 2001, National Environmental Protection Council 2004). Thus, introduced psittacines may threaten Hawai`i's endangered loulu palms (*Pritchardia* spp.) and other native trees and shrubs with large seeds.

On Maui, direct competition between mitred parakeets and native birds has been observed in the displacement of frigate birds (*Fregata minor*) from roosting areas and in competition with shearwaters (*Puffinus* spp.) and petrels (*Pterodroma* spp.) for nesting sites in cliff-side burrows (MISC 2002) and may also be in conflict with Hawaiian black noddies (*Anous minutus*). A similar situation may exist with the burrowing parakeets on the Kona Coast. Roughly half of all psittacines include flower parts, nectar, or pollen in their diets and in Hawai`i, there is concern that these species could feed on native ohia trees (*Metrosideros polymorpha*) and other native flowering plants and might devastate native honeycreeper populations by competing for nectar resources (Loope et al. 2001).

A variety of parrot species are well-known agricultural pests in their native ranges typically targeting a wide variety of fruits, grains and oilseed crops (Bomford 1992). Habitats of about 30% of psittacines included orchards, plantations or croplands, but <4% included major Hawaiian crops such as coffee plantations or flooded taro fields. Cultivated tropical fruits, also important Hawaiian crops, were specifically included in summaries of diets for <10% of species; mango, citrus, banana and papaya were most frequent. Maize or various nut crops were included in diets of about 20% of species (T. Pratt and J. Foster, unpublished data). The agricultural impact of parrots in Hawai`i has not been assessed, but the potential for damage by existing species is evidenced by the fact that over 70% (17) of the 24 psittacines recently sighted in the state were identified as agricultural pest species, or as feeding on cultivated crops, orchards, etc. in their native ranges (Table 4). In a recent survey of farmers across Hawai`i, only 2% of respondents were concerned about damage from parrots to fruits and vegetables, such as corn, bananas, and papaya (NWRC, unpublished data). Our analyses suggest that the species most likely to emerge as agricultural pests in the US, if established, were the *Aratinga* parakeets and *Amazona* parrots of South America, cockatoos and corellas (*Cacatua* spp.) from Australia, lovebirds from Africa, and *Psittacula* parakeets from Africa and Asia.

The devastating impact of introduced parasites and disease on native Hawaiian forest birds has been well documented (Berger 1975; Van Riper et al. 1986, Van Riper and Scott 2001, Van Riper et al. 2002) and parrots can carry a variety of diseases that could impact native forest birds. As potential disease vectors, wide-ranging parrot populations threaten not only native bird species, but also poultry flocks, cage birds, aviculture, and human health. Diseases potentially transmissible to man or other birds include avian influenza, psittacosis (also known as ornithosis, chlamydiosis, and parrot fever), salmonellosis, pseudotuberculosis, tuberculosis, avian malaria, avian pox, erysipelas, pasteurellosis and Newcastle's disease. Of these, the first five are potentially of importance to human health. It has not yet been determined if any of the free-ranging parrots in Hawai`i carry these diseases. Since 2002, restrictions aimed at reducing imports of birds potentially infected with Newcastle disease and West Nile Virus into Hawai`i have been imposed. However, thousands

of birds have recently been imported into the State each year (Foster 2005). Currently, avian influenza if of great concern worldwide and there is widespread recognition of the risk of disease transmission associated with wildlife translocations and international trade in birds (Fevre et al. 2006). For highly pathogenic avian influenza (subtype H5N1), there is a potential for pandemic spread and cross-species transmission.

## CONCLUSION

Every invasive species was first introduced, and introduction effort is clearly the most important influence on the establishment of exotic birds in general, and of parrots in particular. Thus, minimizing the frequency of introductions, and the numbers of parrots released, will be the best way to prevent exotic parrots from becoming established in the future. This basic principle can be broadly applied; in their review of the status of a wide variety of exotic wildlife in North America and Europe, Jeschke and Strayer (2005) concluded, "…once a vertebrate is introduced, it has a high potential to become invasive. Thus, it is crucial to minimize the number of species introductions to effectively control invasive vertebrates". Because invasive species are rarely eradicated, and their damages will be borne for long periods, prevention is the best cure and will likely be the most cost-effective cure in the long run (Keller et al. 2007). As advocated by Loope et al. (2001), the list of birds permitted into Hawai'i should be reassessed to eliminate species with high risk of invasion. Past history of successful introduction, and trends in distribution and abundance of introduced populations are a reliable basis to identify parrots that pose a high risk of invasion. We used this along with three life history traits (extent of altitude range, diet breadth and degree of migration) to screen psittacines and identified 22 species which appeared most likely to establish naturalized breeding populations, if introduced. Currently, 17 of these are conditionally approved for import, meaning that permits may be granted for "individual possession, businesses, or institutions" (Hawai`i Department of Agriculture HRS Chapter 71). Policy makers might consider these as potential candidates for early detection surveillance, rapid response planning, or stricter import regulations.

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