**WG3 Final Report**

The main objective of WG3 is to integrate all available evidence to determine what factors limit *distribution*, *abundance* and *population growth rate* of parakeets across Europe, in order to inform policy. For this purpose, we have three main tasks, and their associated milestones, namely:

**Task 1.** To conduct a systematic review of existing information and data in terms of data type, quality, and geographic coverage,

**Milestone 1:** Report on parakeet data in existing information-systems and recommend key analyses.

**Task 2.** To prioritize utility of data for informing essential demographic parameters and identify important data gaps that need filling, and

**Milestone 2:** Recommend data/studies required to fill knowledge gaps and align to STSMs.

**Task 3.** To synthesize accumulated data sets (to include initially those in climate, land-use, habitat availability and diversity, genetic diversity and evolutionary origin) and explore temporal and spatial patterns to identify factors limiting parakeet population distribution and growth across Europe (links with WG1).

**Milestone 3:** Publish analysis identifying limiting factors.

WG3 was very active during the whole Parrotnet project. During the first year of the COST ACTION, we were able to identify the main sources of data available to deep on factors affecting demography and, thus, distribution of invasive parrots across Europe. Researchers, managers, and NGOs performing long-term censuses, roost counts, or mark-recapture programs involving parrots or parakeets across Europe were all identified and contacted to collaborate with the aim of sharing information to improve our understanding of the demography and distribution of exotic parrots (Task 1). In parallel, this work also allowed us to identify the main gaps that should be covered as well as the different ways we could deal with the lack of information (Task 2). Briefly, we have collected information about the population size of exotic parrots (mainly Ring-necked RNP and Monk MP parakeets) across Europe, covering 27 countries. This data have been published in a scientific journal for the RNP (Parau et al. 2016 The Open Ornithology Journal) and are in the process of publication for the MP (Postigo et al.). Information about the year of the first introduction of RNP and MP was also updated and expanded, covering 166 cities across 14 EU countries for the first species and 87 cities across 12 EU countries for the second one. Besides, we collected data on the status (established or failed) of 190 populations across 35 EU countries to analyse factors affecting their success or failure. Finally, data about worldwide non-native Amazon parrots distribution was compiled and published in a scientific journal (Mori et al. 2017 Animal Biodiversity and Conservation). Demographic information of parrots available in the scientific and grey literature was also compiled and reported. This survey was a cue to detect the main gaps that need to be covered. In particular, we found a lack of long-term information to obtain reliable estimates of survival, a key demographic aspect for long-lived species such as parrots. All this information is available in the STSM reports (3) presented by Liviu Parau and Rachel White.

Thanks to the many research interests shared among Parrotnet members, we were very fruitful in combining different skills, abilities, and data to highly advance in our knowledge about factors governing the distribution and demography of invasive parrot populations across Europe (Task 3). Due to their importance as invaders as well as the availability of accurate data, this task was addressed using the RNP as a study model. Today, we have a rather good picture about drivers of distribution as well as good data to inform policy makers about the best and most effective management actions to control or eradicate this species (and other parrots). This last objective, which is indeed one of the main objectives of WG1, should be undoubtedly related to our work, as an effective management of an invasive requires not only know about the impact and social perception, but also a good understanding of the demographic dynamics of the populations.

**Factors limiting the distribution of parrots across EU**

The paper of Strubbe et al (2015) was the cornerstone in the understanding of factors determining the distribution of RNP in Europe. In this paper, authors show that the phylogenic origin of parakeets (African vs Asian), as well as climatic (temperature and precipitation gradients) and human-footprint variables,  were important to predict the distribution of this species across the invasive range in Europe. Cardador et al. (2016) went one step forward and, combining niche modeling with trade data, showed that the distribution of RNP across Europe was mainly explained by the pure effects of geographical origin of propagules and year of first importation (reflecting time since the first introduction) and the joint effect of environmental suitability and year of first importation, but not by propagule pressure as a whole. However, the role of propagule pressure was highlighted when only taking into account the fraction of individuals whose niche fitted European conditions (Asian ones). A genetic screening of

European and North American introduced populations of the also highly invasive MP indicates the same pattern, suggesting that propagules came from a restricted native range despite the fact that the species has been imported from several South American countries (Edelaar et al., 2015).

Although previous studies were important to understand large-scale distribution patterns of RNP, micro-habitat characteristics can highly affect the habitat selection patterns of the species at smaller scales. In this sense, using dynamic distribution models, Le Louarn et al. (under review) have shown that the occupation of breeding sites by RNP was largely affected by the density of particular exotic tree species in the surrounding, in particular those providing nesting sites and food. Interesting, although this was the most important variable always, there are other ones that can become relevant in particular years.

Once factors explaining the distribution of the species have been assessed, we characterized the spatio-temporal trend in population growth and geographic spread of RNP across EU, to explore the potential role played by environmental, anthropogenic and contagion effects on the variation of these patterns (Cardador et al. in prep). For these purposes, data compiled for the Iberian peninsula during the last 100 years were used. Results show that the occupation pattern of RNP is better described by models that do not include extinctions across the Iberian range, while its spatial spread depended not only on the dispersal characteristics of the species but also on environmental and anthropogenic factors that increase or decrease its diffusion ability. Models predict more spread in hotter areas, with intermediate precipitation and intermediate levels of urbanization. Notably, the effect of environmental similarity with native ranges was not significant in models receiving higher support, and no clear pattern of climatic niche dynamics of occupied sites throughout time was either found.

**Wildlife trade: patterns and invasion risk**

Due to the importance of trade as a current source of invasive species and to explain distribution patterns of some species such as RNP, our WG devoted some efforts to understand trade patterns, consequences, and associated invasion risk.

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Su et al. (in prep) collected data on traded bird species in markets of countries belonging to three continents (Spain and Portugal (Europe), Taiwan (Asia) and Australia) to evaluate if they were a random sample of the biodiversity of each country or, contrarily, belongs to particular families. Results show that species of three bird families (Psittacidae, Estrildidae, and Fringillidae) are more commonly transported in the three continents than expected under a random model. Moreover, 121 species were common to the three markets, which points to the high potential of trade to homogenize biodiversity.

The recognized key role of international wildlife trade as a major source of current biological invasions worldwide contrasts with the absence of studies aimed at testing the effectiveness of trade regulations to reduce the entrance of non-native species. Thus, Cardador et al. (in prep) have evaluated whether the European ban that prohibited the importation of wild birds in 2005, initially aimed at avoiding the spread of avian flu, have affected the risk of avian invasions in two neighboring European countries (Spain and Portugal). Results show that the number of newly introduced species per year increased exponentially during the study period until the ban (2005), to drastically drop after this year. Thus, the EU blanket ban proved to have been effective by acting at the earliest stages of the invasion process (transport and introduction). However, trade bans can have unexpected effects. In Cardador et al. (in prep), we have shown that the two main continental bans (US ban in 1992 and EU ban in 2005) have generated geographic redirections in trade, with important consequences on worldwide invasion risk. While a number of parrots traded internationally remained largely constant, changes in trade destination occurred. Consequently, the world surface predicted at risk of parrot invasions increased with successive bans. Of concern, a redirection of trade toward developing countries was observed. Attention should be paid on the mismatch between the global requirements of invasion management and the regional scales governing trade regulations.

**Factors limiting the demography of parrots across EU**

Demographic information about invasive parrots was rather scarce at the beginning of this COST action. Thus, we have encouraged the analysis and publication of data available and the interaction between researchers with different skills. As a result, we have two manuscripts under review with robust estimates of survival rates for the RNP and the MP (Senar et al., Senar et al.), which was the main gaps to properly study the demography of these species in their invasive ranges. We also shared long-term population data obtained in different cities in Central EU to estimate population growth rate of RNP across its invasive range. Using information for successful populations and linear regression procedures and state-space models, we have found that all of them share the near the same $\lambda$ (1.203; 95% CI=1.172-1.234), supporting a homogeneous population growth across EU (Sánz-Aguilar et al. in prep). Moreover, we fitted piecewise state-space models to the data of the three best-monitored populations (Wiesbaden, Brussels, and Amsterdam) to evaluate the potential existence of lag phases in population growth (i.e. lower population growth rates in the early stages of invasion). Comparing piecewise and exponential models, we show that both exponential and piecewise models were equally supported. However, all the piecewise models estimated higher slopes (i.e. higher population growth rates) during the first period following the establishment of the species, which is in disagreement with a lower growth rate following colonization (i.e. the lag hypothesis) (Sánz-Aguilar et al. in prep).

One important application of demographic models is to assess the effectiveness of management actions. In this sense, we have collected information about management of exotic parrots across the world to estimate their effectiveness through PVA models. Results support the importance of prevention as the most effective way to halt invasive parrots. During the first years after introduction, and even at the earliest years after establishment, populations are normally small, so eradication is a feasible measure. To be effective, management actions should be focused on eliminating adult birds (by shooting), efforts invested in reducing reproductive output being much less effective due to their lower demographic impact. One important point that should be seriously considered is the public perception of these charismatic species, so strong education programs should be performed to make the people aware about the impacts associated to invasive species.

STSMs were one important instrument to fulfill the different tasks of our WG3. Below, we include a list of STSM performed to deal with WG3 objectives, with a brief resume of their aims.

**1.** **Liviu Pârâu** (supervisor: Dr Julia Schroeder. Max Planck Institute for Ornithology, Germany) 2014. To review spatial and temporal demographic data from multiple sources (published papers, grey literature, data from members of ParrotNet) and identify data gaps and contact people who can fill these gaps.

**2.** **Liviu Pârâu** (supervisor: Dr Julia Schroeder. Max Planck Institute for Ornithology, Germany) 2014. To synthesize demographic data sets and identify habitat factors limiting the spread and establishment of RNP populations in Europe. To update information on population size for countries where data was not available or not updated.

3. **Dr Rachel White** (supervisor: Dr Julia Schroeder. Max Planck Institute for Ornithology, Germany) 2014. To review datasets and types identified during the first two weeks of L. Parau's STSM, assisting in the further identification and collection of data sets and data types if necessary. To update and expand information about year of introduction of RNP and MP

4. **Liviu Pârâu** (supervisors: Dr Michael Wink & Dr. Michael Braun, Heidelberg University, Germany) 2015. To collect data on demographic parameters of RNP populations in Europe and local weather.

5. **Liviu Pârâu** (supervisors: Dr Michael Wink & Dr. Michael Braun, Heidelberg University, Germany) 2015. To publish data on the current distribution and status of the non-native RNP *Psittacula krameri* in Europe

6. **Matteo Lattuada** (supervisors: Dr. Martina Carrete & Dr Laura Cardador, Estación Biológica de Doñana CSIC, Spain). To share ideas and available data to evaluate whether continental trade bans could have changed the international trade of parrot to other countries whose habitat suitability would allow the establishment of new invasive populations.

7. **Marine Le Louarn** (supervisor: Dr. Diederik Strubbe, University of Antwerp (Belgium) 2015. To create a methodological framework that allows for a rigorous comparison of parakeet habitat selection between Belgium and France. To set up a list of local-scale environmental factors that influence RNP distribution during the breeding season.

8. **Shan Su** (supervisors: Dr José L. Tella & Dr Martina Carrete, Estación Biológica de Doñana CSIC, Spain) 2015. To compare patterns of trade in parrots and other exotic bird species across three continents (Europe, Asia, and Australia)

9. **Álvaro Luna** (supervisor: Dr. Luis Reino. CIBIO Research Center in Biodiversity and Genetic Resources, Portugal) 2015**.** Sharing methodologies for measuring space use and reproductive biology of the RNP in Lisbon (Portugal).

10. **Dr Juan Masello** (supervisor: Dr Igor Berkunsky, Universidad Nacional del Centro , Argentina) 2016. To understand how parrots and parakeet populations adapt to disturbance and change in their native ranges in order to be able to disentangle the processes that favour parakeet expansion in Europe

11. **Dr Petra Quillfeldt** (supervisor: Dr Igor Berkunsky, Universidad Nacional del Centro , Argentina) 2016. To understand how parrots and parakeet populations adapt to disturbance and change in their native ranges in order to be able to disentangle the processes that favour parakeet expansion in Europe

12. **Dr Ana Sanz Aguilar** (supervisor: Dr. Simone Tenan, MUSE- Museo delle Scienze, Trento, Italy**)** 2016. To explore population growth rates of the rose-ringed parakeet (*Psittacula krameri*) across Europe, evaluate the potential existence of initial lags in population growth using data on population counts and estimate juvenile and adult survival, parameters unknown for this species.

13. **Dr Laura Cardador** (supervisor: Dr. Ana Rodrigues, Centre d'Ecologie Fonctionnelle & Evolutive (CNRS), France) 2016. To characterize the spatiotemporal trends in population growth

and geographic spread of the RNP (*Psittacula krameri*) across Europe, focusing on the potential role of environmental, anthropogenic and contagion effects on the variation of these patterns.

14. **Dr Esra Per** (supervisors: Dr José L. Tella & Dr Martina Carrete, Estación Biológica de Doñana CSIC, Spain) 2017. To collect information about management of exotic parrots across the world and develop PVA models to assess their effectiveness.

Most of the results of WG3 work has been published in high-quality scientific journals or remain under preparation. A list of publication is included below:


1. Edelaar, P., Roques, S., Hobson, E.A, Gonçalves da Silva, A., Avery, M.L., Russello, M.A., Senar, J.C., Wright, T.F., Carrete, M. & Tella, J.L. 2015. Shared genetic diversity across the global invasive range of the Monk parakeet suggests a common restricted geographic origin and the possibility of convergent selection. Molecular Ecology 24: 2164-2176.
2. Strubbe, D., Jackson, JH., Groombridge, J. & Matthysen, E. (2015) Invasion success of a global avian invader is explained by within-taxon niche structure and association with humans in the native range. Diversity and Distributions 21, 675-685
3. Cardador, L., Carrete, M., Gallardo, B. & Tella, J.L. 2016. Combining trade data and niche modelling improves predictions of the origin and distribution of non-native European populations of a globally invasive species. Journal of Biogeography 43, 967-978.
4. Pârâu, L.G., Strubbe, D., Mori, E., ...Wink, M. 2016. Rose-ringed Parakeet Populations and Numbers in Europe: A Complete Overview. The Open Ornithology Journal
5. Cardador, L., Lattuada, M., Strubbe, D., Tella, J.L., Reino, L., Figueira, R. & Carrete, M. 2017. Regional bans on wild-bird trade modify invasion risks at a global scale. Conservation Letters.

**6.** Berkunsky, I., Quillfeldt, P., Brightsmith, D.J, Abbud, M.C., Aguilar, J.M.R.E., Alemán-Zelaya, U, Aramburú, R.M., Arce Arias, A.Balas McNab, R., Balsby, T.J.S, Barredo Barberena, J.M., Beissinger, S.R., Rosales, M., Berg, K.S., Bianchi, C.A., Blanco, E., Bodrati, A., Bonilla-Ruz, C…Masello, J.F. 2017. Current threats faced by Neotropical parrot populations. Biological Conservation 214, 278-287.

7. Mori, E., Grandi, G., Menchetti, M. ...Ancillotto, L.(2017) Worldwide distribution of non–native Amazon parrots and temporal trends of their global trade. Animal Biodiversity and Conservation

8. Su, S., Carrete, M., Vall-llosera, M., Blackburn, T.M., Cassey, P. & Tella, J.L. (in prep) East

versus West: Cultural and historical influences on alien species composition in bird trade markets.

9. Cardador, L., Abellán, P., Tella, J.L., Anadón, J.D. & Carrete, M. (in prep) The EU European blanket trade ban on wild birds drastically reduced invasion risks without effects in local pet markets

10. Cardador, L., D. Strubbe, M. Carrete & Rodrigues, A. (in prep) Spatiotemporal trends in population growth and geographic spread of the RNP (*Psittacula krameri*) across Europe: potential role of environmental, anthropogenic and contagion effects on the variation of these patterns.

11. Le Louarn, M., Clergeau, P., Strubbe, D. & Deschamps-Cottin, M. (under review) Success in the city: dynamic distribution models highlight temporal variations and differing ecological requirements of native range-shifting and non-native invasive birds. Journal of Avian Biology.

12. Senar estimates of survival rates for the RNP

13. Senar estimates of survival rates for the MP

14. Sánz-Aguilar, A., Strubbe, D., Shwartz, A., Cardador, L., Carrete, M. & Tenna, S. (in prep). Determinants of population growth rates in the invasive population of RNP across EU.

15. Sánz-Aguilar, A., Strubbe, D., Shwartz, A., Cardador, L., Carrete, M. & Tenna, S. (in prep). Absence of lag-phases after the establishment of an invasive species in EU.

16. Per, E., Tella, J.L. & Carrete, M. (in prep). Assessing the effectiveness of management of exotic parrots: A PVA insight to guide managers.