Eurasia Specialized Veterinary Publication

**Entomological Research Letters**

**ISSN: 3108-639X**

2024, Volume 4, Issue 1, Page No: 86-95
Copyright CC BY-NC-SA 4.0
Available online at: www.esvpub.com/

# Individual Floral Choices Scale into Pollination-Network Structure Through Repeated Insect Foraging Decisions

**Amira Khalil[1]*, Sara Fathy[1], Mahmoud Adel[2], Hany Nabil[3], Rania Mostafa[4]**

[1]Department of Pollination Networks and Foraging Decisions, Faculty of Life Sciences, Alexandria University, Alexandria, Egypt.
[2]Department of Individual Choice and Network Structure, Faculty of Biosciences, Cairo University, Cairo, Egypt.
[3]Department of Pollinator Behavior and Network Ecology, Faculty of Sciences, Mansoura University, Mansoura, Egypt.
[4]Department of Floral Choice and Pollination Dynamics, Faculty of Life Sciences, Helwan University, Cairo, Egypt.

***E-mail** ✉ amira.khalil@alexu.edu.eg

**ABSTRACT**

Pollination networks are commonly analysed as sets of realized plant–pollinator links, whereas the behavioural processes producing those links occur through sequential decisions by individual foragers. This scale mismatch makes it difficult to determine when network structure reflects persistent individual choice, changing resource opportunity, or aggregation across heterogeneous insects. This article develops an ecological framework that separates floral valuation, learning, constancy, switching, exploration, repeated visitation, pairwise link realization, and network emergence. These processes are treated as analytically distinct rather than as interchangeable descriptions of preference. The central proposal is that individual floral decisions contribute to network structure only through repeated realization within an opportunity set constrained by floral availability, phenology, morphology, competition, and observation scale. Consequently, an observed network edge is not equivalent to a cognitive preference, and network rewiring is not direct evidence of individual switching. The framework predicts that network-level interpretation should improve when behavioural persistence is measured across explicitly defined temporal windows and individual trajectories are nested within repeated community sampling. It identifies key validation needs, including separation of visitation from pollen transport, individual from colony-level inference, and behavioural updating from species or resource turnover.

**Keywords:** Pollinator foraging, Flower constancy, Floral valuation, Interaction rewiring, Plant–pollinator networks, Behavioural scaling.

**Received:** 16 May 2024
**Revised:** 13 June 2024
**Accepted:** 16 June 2024

**How to Cite This Article:** Khalil A, Fathy S, Adel M, Nabil H, Mostafa R. Individual Floral Choices Scale into Pollination-Network Structure Through Repeated Insect Foraging Decisions. Entomol Appl Sci Lett. 2024;4(1):86-95. https://doi.org/10.51847/S85HXkEl24

## Introduction

Pollination networks compress many encounters into links between plant and pollinator taxa. That representation is ecologically useful, but it can obscure the behavioural grain at which encounters are generated. Individual pollinators differ in sensory experience, reward history, learning, morphology, and realized diet, so species-level interaction frequencies need not arise from one representative decision rule. Individual-level trait distributions can consequently provide information about interaction responses that is lost when heterogeneity is reduced to population means [1]. The unresolved problem is how such individual variation becomes recurrent plant use and, eventually, network structure.

**© 2024 Entomological Research Letters**

A second difficulty concerns time. Plant–pollinator networks can turn over rapidly, with links appearing, disappearing, or being reassigned among sampling periods [2]. Yet a changed link may result from active behavioural switching, altered phenological overlap, partner abundance, spatial co-occurrence, or observation procedure. Network rewiring is therefore a pattern requiring explanation, not a direct measurement of cognition. Similarly, theoretical synthesis of mutualistic-network resilience identifies rewiring as only one among several processes that can influence persistence [3]. Increased rewiring cannot automatically be interpreted as greater adaptability or ecological benefit.

This article proposes a scale-explicit framework in which floral valuation, learning, switching, and repetition are distinct decision components whose consequences can accumulate into interaction structure only when ecological opportunity permits. The contribution is not a universal insect decision algorithm. Rather, it specifies where behavioural evidence licenses inference across levels and where the transition from an individual choice to a network edge remains contingent on ecology, taxon, temporal resolution, and measurement.

*Theoretical methods*

The framework was constructed by organizing the selected evidence according to its primary observation unit: individual choice, repeated individual use, pairwise plant–pollinator interaction, or community network. Evidence was compared across three inference boundaries: choice versus realized visitation, visitation versus pollen transport or functional pollination, and temporal link change versus demonstrated individual switching. These distinctions are necessary because alternative observation methods can reconstruct different networks. In wild bees, pollen-based and visitation-based reconstructions differed, and pollinator sex also altered recovered network structure [4]. A network edge is therefore treated here as an evidence object whose biological interpretation depends partly on how it was observed.

No empirical transition probabilities, coefficients, or network parameters are estimated. Instead, the article develops a proposed logical sequence in which a forager evaluates detectable floral alternatives; experience alters subsequent information use; persistence or exploration changes recurrence of visits; recurrence contributes to pairwise link frequency; and those links are aggregated with the behaviour of other individuals into network structure. Every transition is conditional on ecological opportunity and observation scale. The individual-to-network bridge is thus a conceptual scaling proposition, consistent with arguments for retaining individual heterogeneity in interaction forecasting [1], rather than an empirically validated mechanistic model.

*Individual floral valuation*

A flower becomes behaviourally relevant after it is encountered and evaluated, but valuation need not constitute an invariant ranking of plant species. Wild bumblebees use both absolute and relative reward evaluation, indicating that acceptance can depend partly on the recent reward environment rather than on a fixed reward threshold alone [5]. Repeated use of one plant therefore cannot automatically be interpreted as stable intrinsic preference: the same reward can acquire different decision value when the alternatives against which it is evaluated change.

Valuation may also incorporate delayed experience. Honey bee foragers altered subsequent pollen-foraging decisions after in-hive experience with unsuitable pollen [6]. This supports feedback from post-collection experience to later source use, while leaving the precise information-transfer pathway unresolved. The framework accordingly separates immediate floral assessment from delayed value updating rather than treating either process as a complete account of later visitation.

Individual phenotype can further condition information acquisition. Bumblebees of different sizes invested differently when learning about flowers under controlled conditions [7]. Prior cue–reward association can also bias subsequent choice: bumblebees primed with a floral odour associated with caffeinated nectar showed an induced initial preference for the target floral type [8]. These findings demonstrate experience-dependent variation in valuation and learning, but neither establishes indefinite field fidelity. The proposed framework therefore treats floral value as a temporary, state- and context-dependent decision variable rather than as a fixed coefficient attached to a pollinator species.

*Learning and constancy*

Learning alters more than remembered reward. In bumblebee visual search, experience changed the allocation of attention toward rewarding floral targets [9]. Repeated visitation may therefore arise partly because previously

learned targets become easier to detect, not solely because their remembered reward value is higher. The framework separates information acquisition from value comparison: both may stabilize repeated use, but they are not equivalent mechanisms.

Constancy also depends strongly on its temporal window. Repeated pollen observations from Bombus terrestris showed that similarity in floral use declined as the interval between observations increased [10]. Bout-scale fidelity can consequently coexist with longer-term dietary change. A forager may appear highly constant within one sequence yet explore or switch over subsequent trips as its experience or resource environment changes. Defining constancy as a binary individual trait would erase this temporal structure.

Constancy should not, moreover, be presumed optimal. An agent-based model found that its performance depended on resource conditions, competition, and social information rather than showing a context-independent advantage [11]. Such modeling does not establish field fitness effects, but it is sufficient to challenge interpretations in which stronger constancy is inherently beneficial. Within the framework, constancy is therefore a persistence state defined jointly by observation window and ecological setting.

Because these distinctions are difficult to retain when evidence is reduced to one label, **Table 1** separates observable forms of constancy from the inferences they can support.

**Table 1.** Distinguishing learned floral persistence from temporary constancy and scale-dependent inference

| **Within-bout stabilization** | | |
|---|---|---|
| **Persistence timescale** | **Learned attentional stabilization** | **Bout-scale floral constancy** |
| **Observed choice evidence** | Search becomes preferentially directed toward previously rewarding floral targets | Consecutive visits disproportionately retain one floral type |
| **Meaning for repeated choice** | Repetition may arise because learned targets are detected more efficiently | Short-term persistence can reinforce one plant–pollinator pairing |
| **Foraging context** | Individual bumblebee forager | Individual forager during a short sequence |
| **Test** | Measure attention and choice separately when alternatives change | State the temporal window used to define constancy |
| **Boundary** | Attention is not identical to reward preference or field fidelity | A single bout does not establish enduring specialization |
| **Standing** | Evidence-supported distinction | Proposed interpretive rule |

| **Across-bout persistence** | |
|---|---|
| **Persistence timescale** | **Inter-bout persistence** |
| **Observed choice evidence** | Similar floral use recurs across episodes |
| **Meaning for repeated choice** | More persistent use provides a stronger behavioural basis for recurrent pairwise links |
| **Foraging context** | Same individual across separated trips |
| **Test** | Re-identify individuals across multiple trips and days |
| **Boundary** | Similarity may decline as time and resources change |
| **Standing** | Evidence-supported pattern |

| **Context updating** | | |
|---|---|---|
| **Persistence timescale** | **Context-updated fidelity** | **Conditional constancy** |
| **Observed choice evidence** | Previously preferred options lose or gain relative use | Consequences of persistence differ with resource distribution, competition, or information |
| **Meaning for repeated choice** | Learning may stabilize use while conditions remain similar yet permit updating | Constancy must be interpreted relative to ecological opportunity |
| **Foraging context** | Forager encountering altered reward or cue conditions | Individual or modeled forager under contrasting resource environments |
| **Test** | Manipulate alternatives while preserving individual identity | Test persistence and exploration against mapped field resources |
| **Boundary** | Laboratory cue learning need not transfer quantitatively to field networks | Model performance is not direct evidence of natural fitness |
| **Standing** | Proposed synthesis | Evidence-supported boundary |

*Switching and exploration*

Switching is often treated as the opposite of constancy, but that binary classification obscures what actually changes. Honey bee pollen and nectar foragers can differ in learning performance depending on reward context [12], showing that foraging task may condition acquisition of new floral information. These differences should

not be converted into immutable cognitive categories, but they argue against assuming one exploration rule across all foraging states.

More importantly, switching can occur along separable behavioural dimensions. In Bombus impatiens, floral cues and flower-handling tactics affected switching decisions, and bees could change one component of flower use while retaining another [13]. Changing a colour-based floral choice while preserving a learned handling routine is therefore behaviourally different from abandoning both a cue and its associated motor tactic. Aggregated network observations ordinarily collapse those routes into the same outcome—a changed interaction.

The proposed framework accordingly defines exploration as sampling that increases information about alternatives, whereas switching is a realized change in the option repeatedly used. Exploration can occur without durable replacement of the current plant, and switching can follow value updating without extensive exploration. Apparent switching may also arise if a formerly used floral option becomes unavailable. Those alternatives must be discriminated before interaction rewiring is attributed to behavioural flexibility.

**Figure 1** therefore treats departure from prior floral use as a diagnostic discordance requiring separation of behavioural updating from altered opportunity, rather than as self-evident switching.

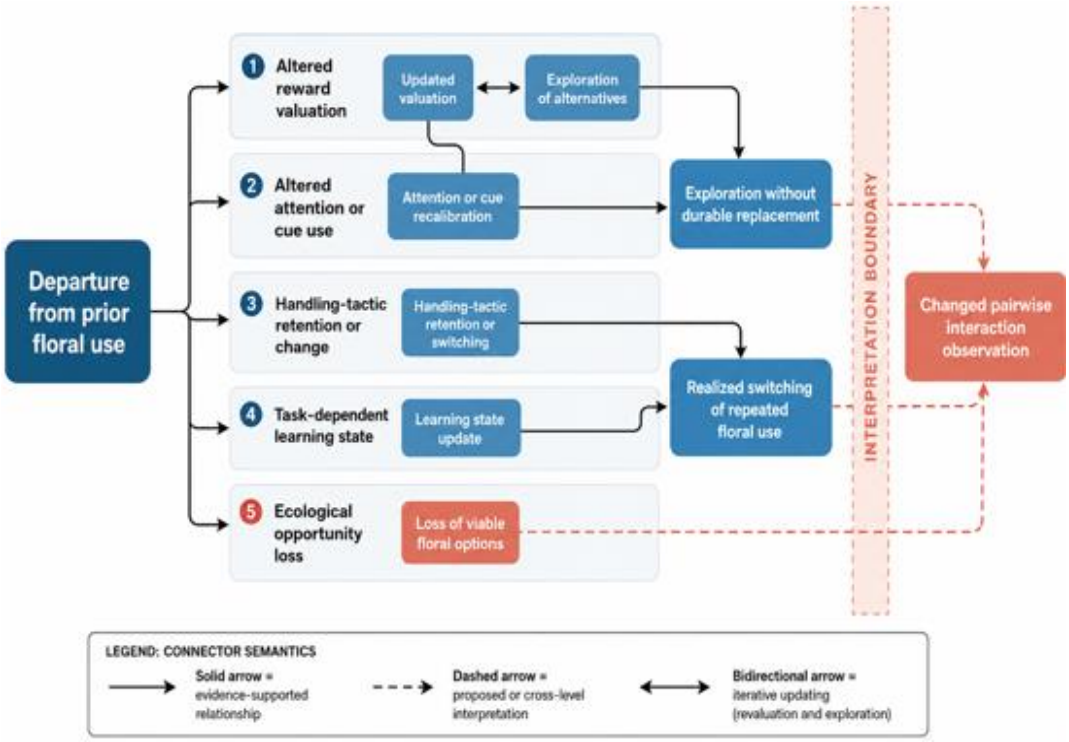



**Figure 1**. Diagnosing apparent floral switching by separating cue change, tactic retention, value updating, and opportunity loss

*Repeated visitation*

Repeated visitation is the critical intermediate level between a single floral choice and a link represented in a network. Wild bees can differ markedly in realized dietary specialization within species, so species-level aggregation may conceal contrasting individual resource-use patterns [14]. Repetition therefore supplies information that an isolated encounter cannot: it indicates whether one plant–pollinator pairing is being reinforced by the same forager or reconstructed from visits made by different individuals.

Recurrence nevertheless remains constrained by opportunity. Temporal metabarcoding of honey bee-collected pollen showed that aggregate diet specificity changed as floral availability changed [15]. Because colony-level pollen records do not retain each forager's decision trajectory, such evidence supports temporal resource tracking at the colony level but cannot demonstrate that particular bees switched plants. The same inference problem arises whenever pooled community interaction counts are interpreted as individual behavioural flexibility.

Scale further changes the meaning of specialization. Local and regional plant–pollinator networks can yield different specialization patterns [16], demonstrating that realized interaction breadth is not invariant to aggregation. The proposed framework therefore characterizes repeated visitation with three identifiers: who

repeats the interaction, over what temporal window, and within what opportunity set. Without these identifiers, a strong link may reflect individual constancy, population heterogeneity, high partner availability, or several processes simultaneously.

**Table 2** adjudicates these alternatives before repeated visits are promoted from observations of floral use to evidence about pairwise interaction structure.

**Table 2.** Adjudicating the behavioural meaning of repeated floral visitation before pairwise link assignment

| | |
|---|---|
| **Individual recurrence** | |
| **Same-individual recurrence** | |
| **Level retaining the recurrence** | Individually identifiable forager |
| **The same insect repeatedly returns to one plant taxon across defined episodes** | |
| **Observable signature** | |
| **Strongest behavioural basis for an individual's recurrent contribution to a link** | Local abundance or site fidelity may constrain apparent choice |
| **Pairwise-link meaning** | **Competing generator** |
| **Track the individual while quantifying available alternatives** | *Evidence-supported inference class* |
| **Population and colony aggregation** | |
| **Within-species heterogeneous recurrence** | |
| **Level retaining the recurrence** | Multiple individuals of one pollinator species |
| **Individuals repeatedly use different plant subsets** | |
| **Observable signature** | |
| **Species-level link weights can hide contrasting individual diets** | Unequal detection or pollen recovery among individuals |
| **Pairwise-link meaning** | **Competing generator** |
| **Preserve individual identity in interaction records** | *Evidence-supported pattern* |
| **Colony-integrated recurrence** | |
| **Level retaining the recurrence** | Social bee colony |
| **Repeated plant use appears in pooled pollen or colony-level records** | |
| **Observable signature** | |
| **Supports colony-level resource use, not an individual decision trajectory** | Recruitment and division of labour may produce the aggregate pattern |
| **Pairwise-link meaning** | **Competing generator** |
| **Pair colony-level sampling with individually marked foragers** | *Proposed adjudication rule* |
| **Opportunity and scale dependence** | |
| **Opportunity-driven recurrence** | |
| **Level retaining the recurrence** | Flower-visiting insect within a changing floral field |
| **Visits concentrate on abundant or temporally available plants** | |
| **Observable signature** | |
| **A strong edge may reflect constrained opportunity as well as preference** | Floral abundance, phenological overlap, or spatial proximity |
| **Pairwise-link meaning** | **Competing generator** |
| **Quantify or manipulate availability before attributing preference** | *Proposed synthesis* |
| **Scale-dependent specialization** | |
| **Level retaining the recurrence** | Pollinator assemblage or interaction network |
| **Interaction breadth changes after spatial or temporal aggregation** | |
| **Observable signature** | |
| **Network specialization is partly conditional on observational scale** | Genuine turnover among places or periods |
| **Pairwise-link meaning** | **Competing generator** |
| **Recalculate interaction breadth across nested scales** | *Evidence-supported boundary* |

*Pairwise plant–pollinator links*

A repeated visit becomes a network link only after individual events are aggregated at a chosen taxonomic, spatial, and temporal resolution. Floral traits can contribute to this filtering. Seasonal field evidence shows that floral

volatile profiles are associated with the organization of plant–pollinator interactions [17]. Such associations support a role for sensory phenotype in partner use, but they do not establish floral odour as an exclusive determinant of a link. Reward, morphology, abundance, phenology, and previous experience remain alternative or interacting explanations.

Persistence also requires partners to be simultaneously available and sufficiently compatible. Across six years, trait matching and phenological overlap were associated with greater spatio-temporal stability and functionality of plant–pollinator interactions [18]. This evidence makes a crucial distinction for the proposed framework: individual valuation operates inside a feasibility envelope. A pollinator cannot maintain a learned association with a plant that is absent, phenologically inaccessible, or incompatible with its foraging morphology. Conversely, feasible overlap does not prove preference.

Taxonomic aggregation adds another boundary. Wild bees and hoverflies contributed differently to plant–pollinator network structure in fragmented habitats [19]. Decision rules inferred mainly from bees should therefore not be generalized automatically to other flower-visiting insect guilds. In this framework, a pairwise link is best interpreted as a realized ecological relation generated jointly by opportunity, compatibility, and repeated behaviour, not as a direct readout of a single cognitive preference.

*Network emergence*

When pairwise links are accumulated across individuals, network structure can emerge without every link requiring a strong or stable preference. Longitudinal analyses indicate that opportunistic attachment can explain important features of plant–pollinator network assembly [20]. Partner availability and encounter opportunity therefore belong inside, rather than outside, any behavioural account of network formation. The proposed framework treats choice as a conditional filter on opportunities, not as their substitute.

Network topology also depends on when and where interactions are sampled. A multilayer analysis showed substantial spatio-temporal variation in species roles and interaction patterns [21]. Consequently, a network assembled over a season is not simply a larger version of a network observed during one week. Temporal aggregation can preserve recurrent edges while masking sequential replacement, and spatial aggregation can combine interactions that no individual ever encountered simultaneously.

Longer temporal comparisons reinforce this caution. A century-scale reconstruction in the subarctic revealed extensive reorganization of plant–pollinator interactions [22]. Such change can reflect altered species composition, phenology, environment, and interaction opportunity; it cannot be assigned retrospectively to learning or switching by individual insects. Network emergence must therefore be separated from network historical change even when both produce different edge sets.

Finally, structural organization and ecological function are not interchangeable. Field evidence indicates that loss of pollinator functional diversity can reduce community-wide trait matching and pollination function even when species-diversity change alone is less informative [23]. The framework consequently ends its behavioural scaling claim at realized network structure unless functional measurements independently justify a further inference to pollen transfer or reproduction.

**Table 3** separates four network states that can look similar in an aggregated interaction matrix but require different biological explanations and different validation data.

**Table 3.** Network states that require different explanations before behavioural choice is inferred from emergent topology

| **Where the pattern originates** | | | **What the network shows** | **How choice is adjudicated** | | |
|---|---|---|---|---|---|---|
| **Network-emergence state** | **Originating level** | **Plausible generator** | **Observed network response** | **Observation needed** | **Inference not licensed** | **Standing** |
| **Opportunity versus behavioral reinforcement** | | | | | | |
| **Opportunity-dominated assembly** | Community opportunity set | Co-occurrence, encounter probability, abundance | New links accumulate as partners become available | Concurrent partner availability and individual encounter histories | Each new edge reflects learned preference | Evidence-supported boundary |
| **Behaviourally reinforced link accumulation** | Repeated individual use | Constancy, updated valuation, | Particular pairwise links recur disproportionately | Individually resolved repeated visits within | Strong edge weight proves an | Proposed cross-level state |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | repeated successful handling | | mapped floral alternatives | immutable preference | |
| **Layer reconfiguration and functional divergence** | | | | | | |
| **Layer-dependent reconfiguration** | Spatial or temporal network layer | Phenology, local abundance, movement, behavioural updating | Species roles and links change among places or periods | Matched individual and community sampling across layers | Layer turnover directly measures switching | Evidence-supported boundary |
| **Structural-to-functional divergence** | Community network and pollination function | Functional composition and interaction identity | Similar richness or topology can accompany different trait matching or function | Independent pollen-transfer or reproductive measurements | Network topology alone establishes pollination performance | Evidence-supported boundary |

Because the same network pattern can be generated through different routes, **Figure 2** keeps behavioural accumulation, ecological opportunity, compatibility, and observation scale in parallel rather than collapsing them into one causal pipeline.

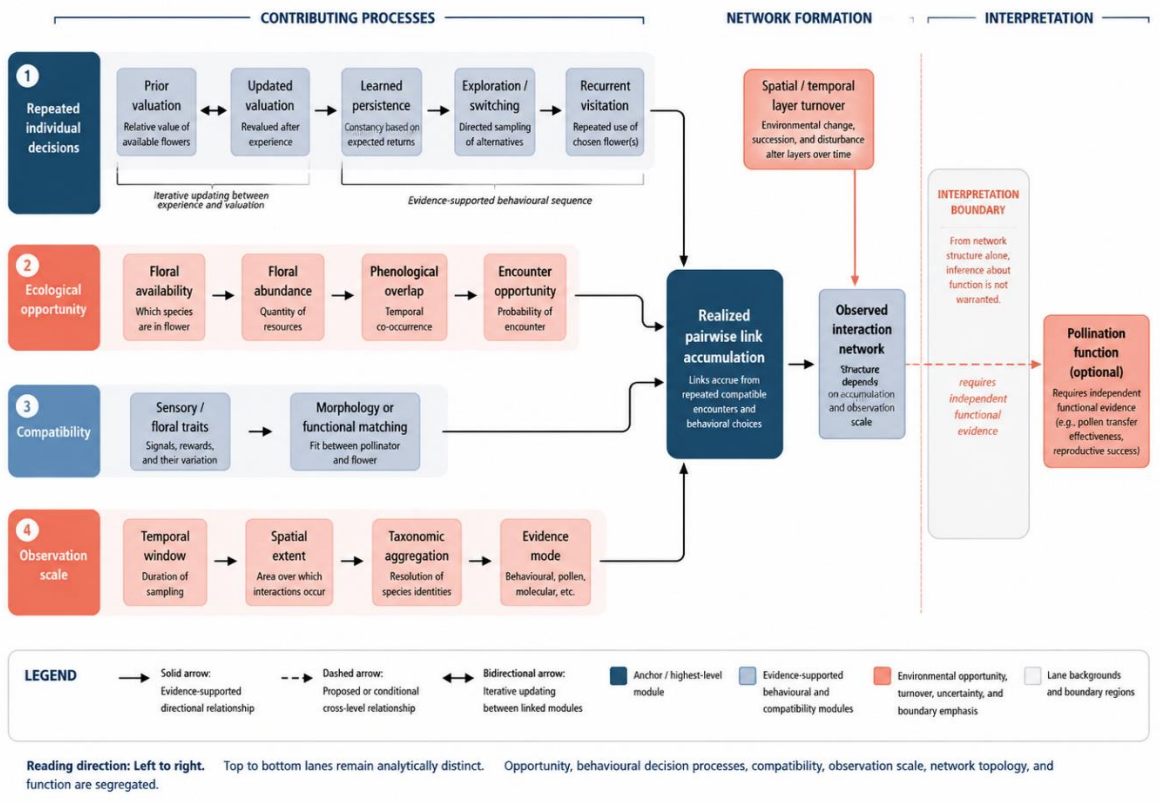



**Figure 2**. Resolving how repeated decisions, ecological opportunity, and observation scale jointly produce an interaction network

*Effects of floral turnover and resource competition*

Environmental change can alter network structure before any pollinator revises a learned choice, because it changes which alternatives exist. Habitat loss has been associated with increased seasonal interaction rewiring [24]. The pattern establishes context dependence of realized links, but increased rewiring should not be described automatically as adaptive flexibility: it may represent constrained substitution following resource loss.

Landscape transformation operates similarly at broader scales. Across landscapes differing in urbanisation and agricultural intensification, plant–pollinator network structure and modeled robustness varied with land-use context [25]. Because robustness outcomes were simulation-derived, they should not be equated with observed extinction or persistence. For the proposed framework, this evidence instead shows that the ecological opportunity field surrounding individual decisions can change systematically with landscape context.

Experimental warming provides a more direct demonstration that altered environment can reorganize opportunity. Warming advanced phenologies and changed traits, interactions, and reproduction in experimental plant–pollinator communities [26]. Transfer to natural communities remains conditional because compensatory behaviour, dispersal, species turnover, and greater environmental heterogeneity may alter field outcomes.

Resource competition can also change the consequences of persistence. Simulated social-bee environments indicate that strong flower constancy can reduce forage diversity under some resource configurations [27]. This is a theoretical cost, not a demonstrated universal field effect. Together, these results support a distinction between changing the menu of available flowers and changing the forager's decision policy. Both can alter the eventual network, but only the latter is behavioural updating.

**Results and Discussion**

The framework resolves a recurring scale problem by placing individual foraging behaviour inside an explicit ecological opportunity set. Floral valuation and learning can stabilize use, while exploration or switching can redirect it; repeated realization then contributes to pairwise link frequency. Yet opportunity-based assembly means that individual decisions are only one generator of emergent topology [20]. The framework is therefore intentionally asymmetric: behavioural evidence can explain some recurrent links, but network structure alone cannot uniquely recover the decisions that produced them.

Temporal interpretation is especially vulnerable to reverse inference. Interaction turnover occurs across short-term, multilayer, and historical representations [2, 21, 22]. Those patterns share the fact of changing edges, not a common behavioural mechanism. A rigorous test of the proposed framework would require marked or otherwise individually identifiable pollinators followed across repeated bouts while floral availability, reward conditions, and community interactions are sampled over the same windows.

Environmental context creates a second confounding route because habitat alteration, landscape transformation, and warming can reorganize realized interaction opportunities [24, 25, 26]. Such changes can produce apparent rewiring even when behavioural decision rules remain unchanged. Future work should therefore quantify the available floral set alongside actual choices rather than inferring flexibility from interaction turnover alone.

The framework also has important taxonomic and methodological limits. Most direct cognitive evidence in the selected literature concerns bees, whereas guild-level network evidence shows that flower-visiting taxa can contribute differently to interaction structure [19]. Sex can alter the reconstructed wild-bee network, and pollen-derived interactions do not reproduce visitation networks exactly [4]. Colony-integrated molecular data likewise reveal resource use without identifying each forager's sequence [15]. These boundaries argue for nested designs linking individual trajectories, population-level resource use, and repeated community networks rather than substituting one level for another.

The key empirical prediction is conditional rather than numerical: when individual persistence is strong, alternatives remain available, and temporal aggregation matches the behavioural window, recurrent individual choices should contribute more clearly to stable pairwise links. When opportunity changes faster than learned preferences can be expressed, network turnover should increasingly reflect ecological filtering rather than observable switching. This proposition is testable, but it has not yet been validated as a general cross-taxon rule.

**Conclusion**

Individual floral choice and pollination-network structure occupy different levels of ecological organization. Connecting them requires more than assuming that preferred flowers become strong network links. The proposed framework identifies repeated visitation as the critical intermediate process while retaining separate roles for learning, exploration, ecological opportunity, partner compatibility, taxonomic composition, and observation scale.

Its principal boundary is equally important: a network edge is not a cognitive state, and a changed edge is not direct evidence of behavioural switching. Network structure can emerge or reorganize because foragers change decisions, because available partners change, or because observations are aggregated differently. Progress therefore depends on designs that retain individual identity while measuring floral alternatives and network dynamics over matched temporal and spatial windows. Such integration would permit the behavioural origins of

network structure to be tested without assigning individual mechanisms to patterns observed only at community scale.

**Acknowledgments:** None

**Conflict of Interest:** None

**Financial Support:** None

**Ethics Statement:** None

**References**

1. Cantwell-Jones A, Tylianakis JM, Larson K, Gill RJ. Using individual-based trait frequency distributions to forecast plant-pollinator network responses to environmental change. Ecol Lett. 2024;27(1):e14368. doi:10.1111/ele.14368
2. CaraDonna PJ, Petry WK, Brennan RM, Cunningham JL, Bronstein JL, Waser NM, et al. Interaction rewiring and the rapid turnover of plant-pollinator networks. Ecol Lett. 2017;20(3):385-94. doi:10.1111/ele.12740
3. Bascompte J, Scheffer M. The resilience of plant-pollinator networks. Annu Rev Entomol. 2023;68:363-80. doi:10.1146/annurev-ento-120120-102424
4. Tourbez C, Gómez-Martínez C, González-Estévez MÁ, Lázaro A. Pollen analysis reveals the effects of uncovered interactions, pollen-carrying structures, and pollinator sex on the structure of wild bee-plant networks. Insect Sci. 2024;31(3):971-88. doi:10.1111/1744-7917.13267
5. Hemingway CT, Pimplikar S, Muth F. Wild bumblebees use both absolute and relative evaluation when foraging. Behav Ecol. 2024;35(1):arad112. doi:10.1093/beheco/arad112
6. Lajad R, Arenas A. Honey bee colonies change their foraging decisions after in-hive experiences with unsuitable pollen. J Exp Biol. 2024;227(1):jeb246233. doi:10.1242/jeb.246233
7. Frasnelli E, Robert T, Chow PKY, Scales B, Gibson S, Manning N, et al. Small and large bumblebees invest differently when learning about flowers. Curr Biol. 2021;31(5):1058-64.e3. doi:10.1016/j.cub.2020.11.062
8. Arnold SEJ, Dudenhöffer JH, Fountain MT, James KL, Hall DR, Farman DI, et al. Bumble bees show an induced preference for flowers when primed with caffeinated nectar and a target floral odor. Curr Biol. 2021;31(18):4127-31.e4. doi:10.1016/j.cub.2021.06.068
9. Robert T, Tarapata K, Nityananda V. Learning modifies attention during bumblebee visual search. Behav Ecol Sociobiol. 2024;78(2):22. doi:10.1007/s00265-024-03432-z
10. Yourstone J, Varadarajan V, Olsson O. Bumblebee flower constancy and pollen diversity over time. Behav Ecol. 2023;34(4):602-12. doi:10.1093/beheco/arad028
11. Hayes L, Grüter C. When should bees be flower constant? An agent-based model highlights the importance of social information and foraging conditions. J Anim Ecol. 2023;92(3):580-93. doi:10.1111/1365-2656.13861
12. Moreno E, Arenas A. Foraging task specialization in honey bees (Apis mellifera): The contribution of floral rewards to the learning performance of pollen and nectar foragers. J Exp Biol. 2024;227(13):jeb246979. doi:10.1242/jeb.246979
13. Baek M, Garcia JS, Papaj DR. Floral cues and flower-handling tactics affect switching decisions by nectar-foraging bumble bees. Anim Behav. 2024;215:163-75. doi:10.1016/j.anbehav.2024.07.010
14. Smith C, Weinman L, Gibbs J, Winfree R. Specialist foragers in forest bee communities are small, social or emerge early. J Anim Ecol. 2019;88(8):1158-67. doi:10.1111/1365-2656.13003
15. Lowe A, Jones L, Brennan G, Creer S, Christie L, de Vere N. Temporal change in floral availability leads to periods of resource limitation and affects diet specificity in a generalist pollinator. Mol Ecol. 2023;32(23):6363-76. doi:10.1111/mec.16719
16. Carstensen DW, Trøjelsgaard K, Ollerton J, Morellato LPC. Local and regional specialization in plant-pollinator networks. Oikos. 2018;127(4):531-7. doi:10.1111/oik.04436
17. Burkle LA, Runyon JB. Floral volatiles structure plant-pollinator interactions in a diverse community across the growing season. Funct Ecol. 2019;33(11):2116-29. doi:10.1111/1365-2435.13424

18. Peralta G, Vázquez DP, Chacoff NP, Lomáscolo SB, Perry GLW, Tylianakis JM. Trait matching and phenological overlap increase the spatio-temporal stability and functionality of plant-pollinator interactions. Ecol Lett. 2020;23(7):1107-16. doi:10.1111/ele.13510
19. Jauker F, Jauker B, Grass I, Steffan-Dewenter I, Wolters V. Partitioning wild bee and hoverfly contributions to plant-pollinator network structure in fragmented habitats. Ecology. 2019;100(2):e02569. doi:10.1002/ecy.2569
20. Ponisio LC, Gaiarsa MP, Kremen C. Opportunistic attachment assembles plant-pollinator networks. Ecol Lett. 2017;20(10):1261-72. doi:10.1111/ele.12821
21. Hervías-Parejo S, Colom P, Beltran Mas R, Serra PE, Pons S, Mesquida V, et al. Spatio-temporal variation in plant-pollinator interactions: A multilayer network approach. Oikos. 2023;2023(8):e09818. doi:10.1111/oik.09818
22. Zoller L, Bennett J, Knight TM. Plant-pollinator network change across a century in the subarctic. Nat Ecol Evol. 2023;7(1):102-12. doi:10.1038/s41559-022-01928-3
23. Hiraiwa MK, Ushimaru A. Loss of functional diversity rather than species diversity of pollinators decreases community-wide trait matching and pollination function. Funct Ecol. 2024;38(5):1296-308. doi:10.1111/1365-2435.14527
24. Lázaro A, Gómez-Martínez C. Habitat loss increases seasonal interaction rewiring in plant-pollinator networks. Funct Ecol. 2022;36(10):2673-84. doi:10.1111/1365-2435.14160
25. Proesmans W, Felten E, Laurent E, Albrecht M, Cyrille N, Labonté A, et al. Urbanisation and agricultural intensification modulate plant-pollinator network structure and robustness. Funct Ecol. 2024;38(3):628-41. doi:10.1111/1365-2435.14503
26. de Manincor N, Fisogni A, Rafferty NE. Warming of experimental plant-pollinator communities advances phenologies, alters traits, reduces interactions and depresses reproduction. Ecol Lett. 2023;26(2):323-34. doi:10.1111/ele.14158
27. Grüter C, Segers FHID, Hayes L. Extensive loss of forage diversity in social bees owing to flower constancy in simulated environments. Proc Biol Sci. 2024;291(2027):20241036. doi:10.1098/rspb.2024.1036