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Public Information Use in Solitary and Gregarious Insects Reveals Socially Derived Decision Making Without Obligatory Sociality

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ABSTRACT

Social information is often discussed through the conspicuous communication systems of eusocial insects, yet many insect decisions are influenced by conspecifics without permanent group living, reproductive division of labour, or cooperative signalling. This perspective argues that the relevant unit of analysis is therefore not social organization alone, but the sequence by which socially derived cues become usable information for a receiver. Evidence from bees, ants, drosophilids, cockroaches, crickets, and blow flies shows that insects can alter foraging, mating, oviposition, shelter, and threat-related decisions after exposure to conspecific behaviour, residues, movement, contact, or communication. These effects are strongly conditional: task difficulty, information certainty, cue dimensionality, social context, sensory access, and cue valence all modify whether socially derived information is used and whether its use is beneficial. The literature also exposes important inferential limits. Responses to conspecific traces do not automatically demonstrate copying, laboratory transmission does not establish field persistence, and neural involvement does not by itself establish adaptive function. This perspective therefore proposes a receiver-centred distinction among cue production, cue availability, sensory uptake, decision weighting, and ecological consequence. Socially derived decision making can occur without obligatory sociality, but its interpretation requires explicit separation of evidence for cue response, social transmission, mechanism, and fitness consequence.

Keywords: Social information, Public information, Insect cognition, Non-eusocial insects, Social learning, Decision making

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Introduction

The most elaborate insect communication systems occur in eusocial lineages, and this visibility has encouraged a tendency to treat social information use as though it were primarily a property of societies. That inference is too strong. Social learning can be implemented through general learning mechanisms, while the ecological setting and organization of interaction determine when those mechanisms are exposed to useful social cues [1]. The existence of specialized recruitment systems in ants or bees therefore cannot define the minimum biological requirements for socially derived decision making.

Insects are especially useful for separating these questions because experimentally tractable learning and decision processes occur in nervous systems that vary widely in ecological and social context [2]. Yet cognitive competence alone is not evidence that a species normally relies on other individuals. Ecological opportunity matters: learning

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in pollinators and herbivores is strongly shaped by resource structure, life history, and the information available during a decision [3]. The same logic should apply to socially derived information. A cue can be detectable but uninformative, informative but costly to sample, or useful only when private evidence is poor.

This distinction is already visible in collective insects. During nest-site decisions, *Temnothorax albipennis* workers altered their relative use of private and social information as certainty changed, rather than expressing a fixed preference for one source [4]. Such evidence should not be generalized directly to solitary taxa, but it establishes an important analytical principle: information use is conditional on decision state. This perspective develops that principle across social organization. It treats eusociality, gregariousness, interaction opportunity, cue production, receiver uptake, and ecological value as separable variables, and it labels their integration here as a proposed synthesis rather than an empirically validated universal model.

Public information beyond eusocial systems

A first reason to move beyond a eusociality-centred interpretation is that even strongly social insects do not use social information uniformly. In *Bombus terrestris*, foragers relied more heavily on social cues when a discrimination task was difficult, indicating that cue use increased when private assessment was less straightforward [5]. In a different bumblebee experiment, social learning could bias choices toward a lower-value option under the imposed reward structure [6]. Social information is therefore neither automatically preferred nor automatically beneficial; its value depends on the relation between cue reliability, task demands, and available alternatives.

Non-eusocial insects extend the argument more directly. Laboratory studies in *Drosophila melanogaster* reported that observing mating decisions could alter later mate choice in females and males, and one experimental transmission design reported persistent socially induced mate preferences [7–9]. These studies are important because they demonstrate social influence on reproductive decisions without eusocial organization, but they do not establish that the effects are equally robust across protocols, populations, sexes, or natural mating environments. The later replication problem considered below is therefore part of the phenomenon to be explained, not a peripheral methodological footnote.

Socially derived information can also cross species boundaries under controlled conditions. In *Drosophila*, prior communal living improved subsequent heterospecific transmission of parasitoid-related information [10]. The result is best interpreted as experience-dependent information transfer, not as evidence for language-like communication or pervasive interspecific signalling in the field. Together, these examples show why “social” should describe the origin or route of information rather than presume an obligately social way of life.

Sources of socially derived environmental information

Social information is not a single sensory commodity. Its availability depends on which individuals produce observable cues, how those cues persist, and how receivers encounter them. In house-hunting *Temnothorax*, information flow through tandem-running networks was highly unequal, with a small and stable subset of workers contributing disproportionately to transmission [11]. That colony structure cannot simply be projected onto transient insect aggregations, but it shows that the number of nearby conspecifics is not equivalent to the amount of usable social information.

Comparative insect biology offers leverage precisely because ecology and social organization vary partly independently. Repeated transitions in social organization and substantial ecological diversity make insects suitable for testing whether cognitive differences are better explained by social or ecological demands [12]. Non-eusocial model insects also show that transient group context can modify behaviour and neural processing without reproductive division of labour or permanent colony structure [13]. Accordingly, the relevant comparison is not “social species” versus “solitary species” alone, but the conditions under which a receiver can access informative products of another individual's behaviour.

The source can also be multimodal. In a *Drosophila* parasitoid-threat paradigm, successful interspecific social learning required multiple sensory inputs and identifiable neural circuitry [14]. This establishes multimodal necessity within that assay, not a general circuit for insect social information. At the decision level, information dimensions can matter as much as information source. *Lasius niger* workers typically prioritized remembered private information over pheromone trails during conflict, but adding unambiguous evidence of superior food quality shifted choices toward the socially indicated option [15]. Thus, location, quality, persistence, and reliability should remain analytically distinct rather than being compressed into a binary private-versus-social label.

Cue production without cooperative intent

A receiver can extract information from a cue even when that cue was not produced as a cooperative message for that receiver. Specialized communication provides a useful contrast. In honeybees, experimentally disrupting the spatial content of waggle dances did not uniformly reduce foraging performance in the tested human-modified environment, and followers reduced their investment in dance information over time [16]. The waggle dance is an evolved recruitment signal, not an inadvertent cue; its relevance here is that even an explicit communication system has context-dependent informational value.

At the other end of the producer–receiver relation, social contact itself can alter learning. In honeybees, contact with a nestmate acted as appetitive reinforcement in an associative-learning paradigm [17]. The experiment establishes reinforcing value for the receiver but does not show that the contacted individual produced a message for that learning event. In the American cockroach, group context could alter or reverse humidity-related shelter preferences compared with isolated choices [18]. Because several interaction-generated processes could contribute, the behavioural effect should not be assigned to a specific signal or cooperative intent without additional evidence.

Deposited traces make this boundary especially important. Female *D. melanogaster* responded strongly to substrates previously occupied by conspecifics, yet the donor-specific pattern did not support a simple conclusion that females were copying relevant public information [19]. A response to a social residue is therefore evidence of cue detection and decision influence; it is not automatically evidence of copying. In *Drosophila suzukii*, larvae and adult-associated host marking altered oviposition decisions differently from egg-density cues, and effects depended on the social trace and its temporal context [20]. Treating "conspecific presence" as a single variable would erase biologically meaningful differences among live animals, developmental stages, residues, and cue persistence.

Crickets provide an even clearer separation between active demonstrator behaviour and receiver learning. *Gryllus bimaculatus* learned in appetitive and aversive social paradigms using living conspecifics, while dead conspecifics could provide sufficient olfactory information in an aversive context [21]. The result does not establish that passive cues are evolutionarily functionless, but it shows that active cooperative production is not necessary for socially derived information to affect learning in that assay. The key distinction is therefore functional for the receiver: who or what produced the cue, whether production was communicative, and whether the receiver can use it are separate questions.

Information uptake in solitary insects

Receiver-side processing provides the strongest reason not to equate social information use with obligatory sociality. In *D. melanogaster*, movement by nearby conspecifics altered threat-related behaviour, and experimental work identified visual-neural components involved in using that activity as safety-related information [22]. This is mechanistic evidence within a defined laboratory threat assay; it does not establish that the same circuitry governs other social decisions or that the behaviour confers a quantified fitness advantage in nature.

Socially relevant information can also be integrated when cues conflict. In the green bottle fly *Lucilia sericata*, controlled bio-robotic demonstrators carrying positive conspecific-like or negative predator-like valence altered selection behaviour [23]. The design demonstrates cue integration under standardized conditions while deliberately simplifying natural multisensory encounters, so field transfer remains an open question.

In gregarious *Periplaneta americana*, social context reaches even earlier stages of sensory processing. A group-induced reversal of odour preference could be reproduced with social odour, and the same context altered antennal-lobe responses to the tested odour mixture [24]. Behavioural valence and sensory representation were therefore linked within the experimental system, but the proposed ecological interpretation—such as avoidance of depleted resources—remains distinct from the demonstrated neural and behavioural effects. Across these studies, information uptake is best treated as a sequence: access to a socially derived cue, sensory processing, integration with private evidence, and behavioural updating. The sequence can operate in insects that are solitary or non-eusocial in social organization, while its ecological meaning remains contingent on taxon, life stage, environment, and decision context.

Gregariousness and context-dependent information value

Gregariousness changes the probability that an insect encounters socially derived information, but it does not determine the value of that information. The honeybee illustrates the distinction. Network-based diffusion analysis showed that waggle-dance communication contributed more strongly to acquisition of novel food locations than to information about familiar locations [25]. The relevant variable was therefore not simply the presence of an elaborate communication system, but whether the receiver faced a decision for which the communicated information added something not already available from experience. Similar logic applies outside eusociality: high encounter rates can increase cue availability while leaving reliability, novelty, and decision relevance unresolved.

Information acquisition should also be separated from information use. Pharmacological manipulation of honeybee dance followers altered dance-following behaviour and subsequent information use in non-identical ways, indicating that attending to a social source and weighting its content are not the same behavioral operation [26]. This separation matters comparatively. A taxon may frequently approach conspecifics yet discount their information, whereas another may encounter conspecifics rarely but make large decision updates when an informative trace is found. Gregariousness therefore describes an interaction environment, not a fixed copying propensity.

The interaction environment itself varies within nominally non-eusocial lineages. Across 20 drosophilid species, social-network properties differed among species and were associated with aspects of historical environment, while several network measures lacked a simple phylogenetic pattern [27]. These laboratory networks do not establish that environmental history caused the observed variation, but they undermine a binary treatment in which a species is simply assigned to a solitary or social category. Realized encounter structure can differ independently of a species-level label and can also vary with sex, density, developmental condition, resource distribution, and experimental geometry.

Neurobehavioral evidence reinforces this multidimensional view. Reviews of fruit flies, cockroaches, locusts, and other non-eusocial insects identify substantial modulation of sensory processing and behavior by social context, while also emphasizing how heavily current mechanistic evidence depends on a small number of experimentally tractable taxa [28]. The cockroach example described above is particularly informative because social odor altered both preference and antennal-lobe activity [24]. Yet neither neural responsiveness nor gregarious aggregation establishes obligatory sociality. They establish that information generated by other individuals can become part of the receiver's decision environment.

The synthesis proposed here therefore separates three variables that are often collapsed: social organization, realized interaction opportunity, and context-dependent information value. Social organization describes the persistence and structure of association; interaction opportunity describes whether socially derived cues are actually available to a receiver; information value describes whether those cues improve, distort, or fail to change the decision relative to available private evidence. These variables can covary, but the reviewed evidence does not justify treating them as interchangeable. This distinction is especially important when comparing solitary insects that meet transiently, gregarious insects that aggregate without eusocial division of labor, and eusocial species with specialized recruitment systems.

Temporal scale adds another boundary. A transient aggregation can create a dense social-information environment for minutes, whereas a deposited chemical trace may remain available after all conspecifics have left. Conversely, repeated association in a colony does not guarantee that every interaction is informative. Comparing species therefore requires measurement of when cues are produced, how long they persist, how frequently receivers encounter them, and whether the underlying environmental state changes before the cue is used. This temporal separation is central to distinguishing gregariousness from information value.

Because prose obscures how the same social exposure can have different consequences depending on taxon, cue type, novelty, and private information, **Table 1** maps the distinct trait–process combinations that must remain separate in comparative interpretation.

Table 1. Gregariousness changes information opportunity, not automatically information value: a trait–process–consequence map for insect decisions

Evidence	Interpretive consequence · Limits and uncertainty	Research or test · Evidential standing	Biological setting
Novel-information recruitment			

Social transmission through dance is stronger for novel than familiar locations	Interaction opportunity is useful when social information adds otherwise unavailable spatial information Specialized recruitment cannot be assumed to represent non-eusocial cue use	Compare the same task at different levels of private familiarity Evidence-supported	Eusocial honeybee foragers
Following–use separation			
Experimental manipulation changes dance following and later information use non-identically	Exposure or attention is not equivalent to decision weighting Pharmacological effects may be pleiotropic and system-specific	Measure encounter, attention, retention, and use as distinct stages Evidence-supported	Eusocial honeybee foragers
Social-odor contextualization			
Group/social odor changes preference and early olfactory representation	Social context can change cue valence before overt choice Laboratory odor mixtures do not establish adaptive field function	Couple sensory measures with field-relevant choice tests Evidence-supported	Gregarious American cockroaches
Variable realized interaction networks			
Network structure differs among species and does not map uniformly onto phylogeny	Species-level social labels underdescribe actual encounter opportunity Laboratory density and environmental history can confound network comparisons	Standardize density and task while retaining phylogenetic controls Evidence-supported	Non-eusocial drosophilid species
Transient social modulation			
Group context alters behavior or neural processing without eusocial organization	Social responsiveness can be state-dependent rather than a permanent social phenotype Evidence is concentrated in a few model taxa	Extend matched paradigms across orders, sexes, and life stages Evidence-supported	Non-eusocial model insects
Social organization × interaction opportunity × information value			
The three dimensions are separable across the evidence base	Similar social exposure may yield different decision effects, and similar decisions may arise under different social systems No validated quantitative scale currently links the three dimensions	Test each dimension independently before inferring a sociality effect Proposed synthesis	Cross-organizational comparison

The proposed separation in **Table 1** also supplies the temporal logic required for a figure: socially derived information must first become available, then be detected and integrated, before it can influence a decision, and each stage can be altered by social organization or context. **Figure 1** makes those conditional transitions and their inferential boundaries explicit.

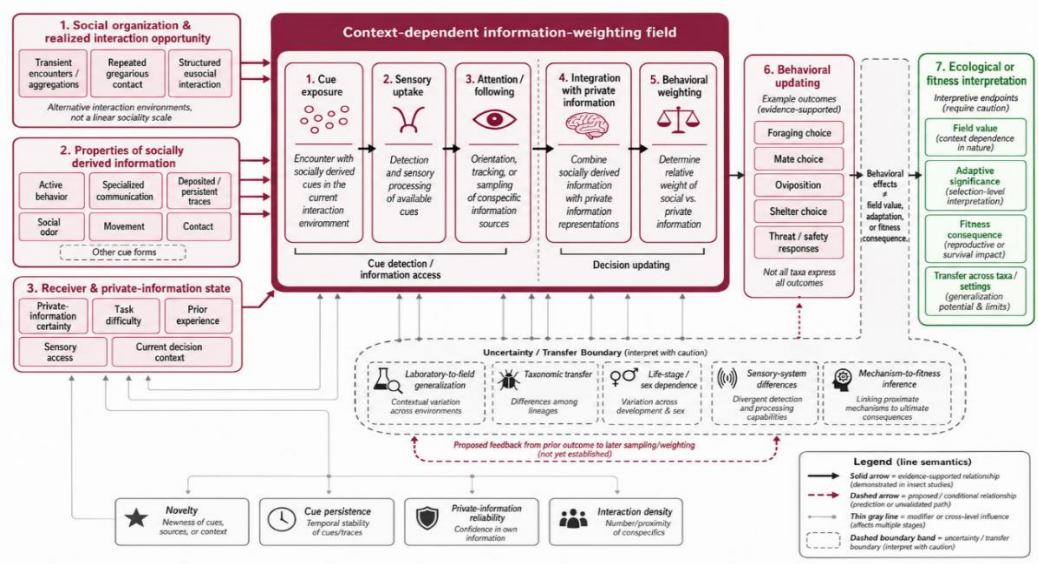


Figure 1. Interaction opportunity, cue access, and receiver weighting determine when socially derived information changes an insect decision

Costs of copying and informational cascades

Once social information is treated as conditionally weighted rather than inherently beneficial, its costs become analytically important. The most obvious cost is following a cue that points toward a poorer option, as demonstrated in the bumblebee foraging task discussed earlier [6]. A second is misclassification: attraction to a conspecific-derived residue can be described as copying even when the evidence supports only cue detection and behavioral bias [19]. A third is amplification, in which interactions among individuals make one preference disproportionately influential.

The American cockroach provides evidence for such nonlinear amplification. In heterogeneous groups, a conditioned minority could determine group shelter consensus under some combinations of minority size and total group size [29]. This is stronger than a simple independent-response model, but it should not automatically be called an informational cascade. A canonical cascade implies that individuals increasingly suppress or override private evidence because previous decisions themselves become informative. The cockroach result establishes minority-driven consensus under controlled conditions; the cognitive information each follower extracted and the extent to which private evidence was abandoned were not shown to constitute a universal cascade mechanism.

The cascade concept also requires temporal evidence. A sequence of similar choices is insufficient if all insects are responding independently to the same shelter, odor, or resource. Demonstrating a stronger cascade interpretation would require showing that earlier choices alter later individuals' information states, that private evidence is correspondingly discounted, and that the effect propagates across successive decisions. Those criteria are more demanding than demonstrating aggregation or consensus. This perspective therefore reserves cascade language for explicitly sequential information dependence and uses social amplification for broader interaction-driven convergence.

Robustness is another cost to inference. A later reassessment of *D. melanogaster* mate-choice copying failed to reproduce the previously expected effect consistently across 368 successful tests and concluded that the phenomenon was less robust than earlier work suggested [30]. That result does not prove that mate copying never occurs. It instead identifies sensitivity to population, protocol, apparatus, or other context as part of the evidence. Earlier positive demonstrations and later negative replication therefore constrain each other.

Across the approved evidence, conditionality is more defensible than a generalized copying rule: uncertainty altered information use in ants, task difficulty altered social-cue reliance in bumblebees, and additional information dimensions changed private-versus-social prioritization in another ant system [4, 5, 15]. These experiments differ in taxon, sensory ecology, decision domain, and social organization, so their qualitative convergence should not be mistaken for a shared quantitative mechanism. The proposed interpretation is narrower: copying costs and cascade-like amplification should be predicted from cue reliability, private-information quality, interaction structure, and repeated exposure, not from sociality category alone.

Comparative predictions across social organization

A comparative theory is useful only if its predictions distinguish social transmission from correlated behavior. Network-based diffusion analysis provides one route because it tests whether acquisition follows measured social connections more closely than specified asocial alternatives [31]. Even then, a network-linked diffusion parameter identifies a transmission pattern, not the psychological mechanism, intentionality of cue production, or adaptive value. Appropriate opportunity networks, temporal acquisition data, and alternative models remain essential.

The proposed synthesis generates several falsifiable comparisons. First, increasing interaction opportunity should increase exposure to social cues, but it should not necessarily increase their behavioral weight. A gregarious aggregation may produce many redundant or unreliable traces, whereas a brief encounter by a nominally solitary insect may provide highly diagnostic information. Second, social information should exert larger effects when private evidence is costly, ambiguous, or outdated, but the direction of the effect should reverse when social cues become misleading. Third, cue persistence should decouple information availability from contemporaneous group presence: residues, host markings, and dead conspecifics can remain informative after the producer has departed. Fourth, specialized recruitment should not be assumed to produce a monotonic ecological advantage. In a field comparison of stingless bees differing in recruitment communication, recruiting species did not simply obtain higher-sugar resources or shorter foraging trips than weakly recruiting species [32]. Because species differ simultaneously in ecology and other traits, this is not evidence that recruitment is ineffective. It is evidence against a one-dimensional prediction that more elaborate recruitment must yield greater performance on every measured foraging endpoint.

Cross-organizational comparisons must additionally preserve life-stage and sensory boundaries. Adult mate choice, female oviposition, worker foraging, and shelter selection do not represent interchangeable decision problems. A volatile residue available to an adult fly, a tactile encounter among cockroaches, and a recruitment dance decoded by a honeybee differ in persistence, modality, spatial range, and receiver experience. A general prediction should therefore survive matched manipulations across different sensory systems rather than depend on identical cues. Failure to separate these levels could falsely attribute a sensory or ecological difference to social organization.

These comparisons lead to a proposed cross-organizational prediction set rather than a ranked sociality continuum. Solitary, gregarious, and eusocial insects should be compared on at least four independently measured axes: encounter structure, cue persistence and modality, uncertainty in private information, and ecological consequence of the resulting decision. Phylogeny, sex, life stage, sensory ecology, habitat, and laboratory density must be treated as potential moderators rather than residual noise. A convincing test would also specify disconfirming patterns in advance. For example, frequent interaction without detectable network-linked transmission would challenge an opportunity-based prediction, while strong transmission under abundant reliable private information would challenge a simple uncertainty-based rule.

Research priorities

The immediate priority is matched-task comparison. Insect diversity provides repeated contrasts in social organization, but existing studies rarely apply the same decision problem and measurement architecture across solitary, facultatively gregarious, and eusocial taxa [12]. Comparative work should therefore manipulate the informational problem while standardizing, as far as biologically meaningful, cue accessibility, reward structure, prior experience, and encounter opportunity. Drosophilid network variation shows why density and realized interaction structure should be measured rather than inferred from a species label [27].

A second priority is experimental separation of cue production from cue use. Oviposition experiments show that conspecific residues can influence choice without demonstrating copying [19]. Different developmental stages and deposited traces can also produce distinct responses [20]. Cricket experiments further show that learning can proceed from dead as well as living conspecifics in specific contexts [21]. Future studies should independently manipulate producer presence, cue age, chemical persistence, demonstrator activity, and receiver access while including nonsocial chemical and environmental controls.

Operational definitions are equally important. Future experiments should specify whether “social information” means any conspecific-derived cue, information inferred from another individual's performance, socially transmitted learning, or an evolved communicative signal. These categories can overlap, but the evidence needed to identify them differs. Predefined criteria for cue origin, receiver response, transmission, and ecological

consequence would make positive and null results more comparable and would reduce the risk that a simple attraction effect is reported as copying.

Third, mechanism and transmission should be connected without being collapsed. Neural manipulations can identify sensory inputs or circuits necessary within a defined laboratory task, as in interspecific *Drosophila* learning [14]. Social-network methods can test whether information acquisition follows interaction opportunities [31]. Neither level establishes the other. Stronger evidence would combine temporally resolved field or semi-field transmission with sensory perturbation, behavioral choice, and ecologically relevant consequences while preserving explicit boundaries between association, mechanism, and fitness.

Finally, replication should be designed as biological inference rather than simple verification. The mate-copying reassessment shows that an effect can be sensitive to protocol or population [30]. Future studies should report sex, life stage, strain or population, group density, cue persistence, prior social experience, and environmental context sufficiently to test heterogeneity. Null results should be retained when cue detectability and statistical power are adequate. The central question is not whether insects are "social enough" to use public information, but which combinations of encounter opportunity, cue reliability, receiver state, and ecological context make socially derived evidence consequential.

Conclusion

Socially derived decision making in insects does not require obligatory sociality, but neither does every response to a conspecific qualify as public-information use or social learning. Evidence across bees, ants, drosophilids, cockroaches, crickets, and blow flies supports a more discriminating interpretation in which social organization, encounter opportunity, cue production, sensory uptake, decision weighting, and ecological consequence remain separate levels of analysis. Their relationships are conditional rather than universally directional.

The perspective developed here therefore proposes replacing a binary social-versus-solitary expectation with a receiver-centred, context-dependent account of information use. Its strongest predictions concern when socially derived cues should alter decisions, when they should be discounted, and when apparent copying may instead reflect cue attraction or interaction structure. Those predictions remain to be tested across matched taxa, natural environments, life stages, and decision domains. The central inference is deliberately limited: insects need not be obligatorily social for other insects to become part of the evidence on which a decision is based.

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