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1 **Coalitions in theory and reality: A review of pertinent variables and processes**

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26 **Abstract**

27 Coalitions and alliances are ubiquitous in humans and many other mammals, being part of the fabric
28 of complex social systems. Field biologists and ethologists have accumulated a vast amount of data
29 on coalition and alliance formation, while theoretical biologists have developed modeling
30 approaches. With the accumulation of empirical data and sophisticated theory, we are now
31 potentially able to answer a host of questions about how coalitions emerge and are maintained in a
32 population over time, and how the psychology of this type of cooperation evolved. Progress can only
33 be achieved, however, by effectively bridging the communication gap that currently exists between
34 empiricists and theoreticians. In this paper, we aim to do so by asking three questions: (1) What are
35 the primary questions addressed by theoreticians interested in coalition formation, and what are the
36 main building blocks of their models? (2) Do empirical observations support the assumptions of
37 current models, and if not, how can we improve this situation? (3) Has theoretical work led to a
38 better understanding of coalition formation, and what are the most profitable lines of inquiry for the
39 future? Our overarching goal is to promote the integration of theoretical and field biology by
40 motivating empirical scientists to collect data on aspects of coalition formation that are currently
41 poorly quantified and to encourage theoreticians to develop a comprehensive theory of coalition
42 formation that is testable under real-world conditions.

43 **Keywords:** Alliances, mathematical models, empirical data, primates, recruitment, fitness,
44 dominance, cooperation

45 **Introduction**

46 Ideally, theory and empirical data should build on each other in a series of mutually reinforcing
47 cycles, generating ever more powerful predictive models that could be tested empirically under a
48 wide range of laboratory and field conditions. The greater precision of our models, and the more
49 focused data sets that would then accumulate, would enable us to identify the key elements
50 underlying a particular behavioral phenomenon. This ideal is rarely met, however, and theoreticians
51 and empirical scientists all too often talk past one another. Part of the reason is a difference in the
52 generality of issues under study: many animal behavior researchers stay close to the empirical
53 material they gather, often focusing on just one or two groups of animals for practical reasons, while
54 asking quite specific questions regarding the observed patterns. In contrast, theoreticians often use
55 formal description to arrive at more general underlying principles of a given phenomenon that can be
56 broadly applied across a variety of taxa and social systems. They do not generally formulate their
57 models in a way that facilitates empirical investigation via precise operationalization.

58 Here we consider the case of coalition formation, an active area of research that seems ready for
59 mathematical modeling. Naturalistic observations are crucial for documenting its distribution across
60 taxa, the variety of forms it takes, the function it serves, and the degree of cognitive complexity it
61 requires. As we will discuss, however, the complexity of the patterns and processes revealed by
62 these naturalistic studies demonstrates the need for a formal theoretical framework to fully
63 understand the evolution and maintenance of coalition formation across the animal kingdom. There
64 is currently a whole suite of modeling approaches available to address such fundamental questions
65 as: Why do some species commonly form coalitions whereas others do not? What are the potential
66 fitness consequences of not participating in all possible coalition opportunities? Can apparently
67 “cognitively complex” coalitionary behavior emerge from simple behavioral rules? Unfortunately, as
68 noted above, the exchange of ideas between empiricists and theoreticians is often hindered by their
69 different goals, background, and use of terminology (Mesterton-Gibbons *et al.*, 2010). Here, we

70 attempt to forge an alliance between theoretical and empirical approaches as the first step toward
71 the long-term goal of achieving a more comprehensive theory of coalition formation.

72 We start by briefly describing patterns of coalition formation within and across species. We next
73 summarize the primary questions addressed by theoreticians, and identify the main building blocks
74 of their models. Then we selectively review the literature on coalition formation with the explicit aim
75 of contrasting empirical data with the assumptions made by theoretical models, pinpointing where
76 these might be overly simplistic, and identifying important parameters that have been poorly
77 quantified in the field. As the literature in this area remains heavily skewed toward the primates
78 (Smith et al., 2010), the empirical data presented here are derived mainly from this taxon. Finally, we
79 propose some profitable lines of inquiry for future theoretical and empirical research on coalition
80 formation.

81 **A Brief Primer on Coalition Formation**

82 The term “coalition” is used in various ways (e.g. an alliance between political parties, Mann, 1993)
83 but, in ethology and behavioral biology, the term typically refers to two (or more) individuals acting
84 together against a third party in an aggressive or competitive context (Harcourt & de Waal, 1992;
85 Figure 1). The term “alliance,” on the other hand, generally refers to a long term relationship
86 characterized by repeated coalitions and high levels of association between the partners, which
87 means that when one partner is in trouble, his or her ally is often nearby and able to help (“alliance
88 behavior based on coalitions”: cf. Feh, 1999; de Waal & Harcourt, 1992). Human coalitions and
89 alliances range from cooperation within a single family to acts of support between nation-states
90 (Chagnon, 1988b; Bowles, 2009; Apicella et al., 2012). On a smaller scale, coalitions and alliances are
91 common in our closest relatives, including for example the chimpanzee (*Pan troglodytes*, review in
92 Muller & Mitani, 2005), as well as a number of non-primate species (reviewed by Harcourt & de
93 Waal, 1992; Smith et al., 2010).

94 (Fig. 1 about here)

95 Animal coalitions and alliances are variable in duration and stability. Coalitions can occur
96 opportunistically on a case-by-case basis (e.g. Bissonnette, 2009; Smith et al., 2010), or they can be
97 observed frequently among the same partners as part of an enduring, long-term relationship (e.g. de
98 Waal, 1982; Packer & Pusey, 1982; Smuts, 1985; Goodall, 1986; Noë, 1986b; Caro & Collins, 1987;
99 Connor et al., 1992; Feh, 1999; Boesch & Boesch-Achermann, 2000; Connor et al., 2001; Boinski et
100 al., 2005; Schülke et al., 2010). One individual may establish year-long, stable alliances with one or a
101 few partners and also participate in opportunistic coalitions with other group members in which
102 loyalties change regularly (Riss & Goodall, 1977; de Waal, 1982; Goodall, 1986; Noë, 1990; Uehara et
103 al., 1994; Connor et al., 2000; Sijtsema et al., 2009). For example, Nishida (1983) and de Waal (1984)
104 have argued that male chimpanzees intervene opportunistically in "political" conflicts and may turn
105 against former allies when it is beneficial to do so.

106 In group-living species, coalitions and alliances are important in both intergroup and intragroup
107 competition. Coalitions for competition against conspecifics from other groups (hereafter "group-
108 wide coalitions") occur when the opponents belong to different social groups (or family units, e.g.
109 Scheiber et al., 2005), whereas within-group coalitions occur when two or more members of the
110 same group compete against at least one other "in-group" member. Group-wide coalitions can be
111 offensive if individuals join forces to oust incumbent male(s) and take over a group (e.g. Pope, 1990;
112 Rood, 1990; Packer et al., 1991; Waser et al., 1994; Ostner & Kappeler, 2004; Wilson et al., 2014), or
113 to conduct a lethal attack on members of a neighbouring group (reviewed by Wrangham, 1999). They
114 can also be defensive, as when group members form a coalition to repel single challengers and/or an
115 out-group coalition (e.g. Feh, 1999). Group-wide coalitions can be very large (e.g. average size in
116 chimpanzees: 13, Watts & Mitani, 2001; hyenas: 14, Smith et al., 2010; human band and tribal level
117 raiding parties range from 10 - 100, Walker & Bailey, 2013; Mathew & Boyd, 2011), in contrast to
118 within-group coalitions, which often involve only two or three partners (reviewed by Smith et al.,
119 2010). It seems likely that group-wide coalition formation provides the only context in which the

120 opposing parties are not mutually dependent on each other (except in dolphins and especially
121 humans, where interdependence extends beyond the level of the group, e.g. Connor et al., 2001;
122 Walker et al., 2011): they usually occur in a clear and unambiguous competitive context and thus are
123 predictably hostile, in contrast to the interactions that occur within groups (Connor et al., 1992;
124 Harcourt, 1992; see below). Group-wide and within-group coalitions, however, are not mutually
125 exclusive phenomena: for example, the need for in-group members to cooperate during between-
126 group encounters is known to profoundly affect the social dynamics of groups, and hence the
127 formation of within-group coalitions (humans: Alexander, 1990; 2014; Flinn et al., 2005; Choi &
128 Bowles, 2007; Bowles, 2009; Rusch 2014; other animals: Watts & Mitani, 2001). Group-wide
129 coalitions have also been suggested as one possible evolutionary precursor of within-group coalitions
130 in animals (Harcourt, 1992), although a formal test of this hypothesis is lacking. Despite the likely
131 interdependence between intra- and inter-group coalition formation, the emphasis of this review is
132 on within-group coalitions, as these have received much more attention both theoretically and
133 empirically.

134 Research on within-group coalitions has historically focused on primates (Kawai, 1958; Kawamura,
135 1958; Hall & DeVore, 1965; Kummer, 1967; Packer, 1977; Riss & Goodall, 1977; de Waal, 1978b).
136 More recent empirical work, however, has revealed that a wide range of mammalian species and
137 some birds engage in coalitionary behaviour (reviewed by Smith et al., 2010), including several social
138 carnivores (e.g. hyenas, *Crocuta crocuta*: Zabel et al., 1992; Engh et al., 2002; Wahaj et al., 2004;
139 ring-tailed coatis, *Nasua nasua*: Romero & Aureli, 2008; African wild dog, *Lycaon pictus*: de Villiers et
140 al., 2003; Domestic dogs, *Canis lupus familiaris*: Ward et al., 2009), some artiodactyls (e.g. fallow
141 deer, *Dama dama*: Jennings et al., 2009; feral sheep, *Ovis aries*: Rowell & Rowell, 1993), some
142 perissodactyls (e.g. plain zebra, *Equus quagga*: Schilder, 1990), one proboscoid (African elephant,
143 *Loxodonta africana*: Lee, 1987), and some birds (e.g. ravens, *Corvus frugilegus*: Seed et al., 2007;
144 *Corvus corax*: Fraser & Bugnyar, 2012).

145 The pattern of within-group coalition formation most commonly reported in the literature is that of
146 one individual intervening in an on-going conflict and aligning itself with one of the original
147 opponents (variously referred as “agonistic intervention”, “agonistic aid”, “fight interference”,
148 “support choice”, de Waal & Harcourt, 1992). Individuals also sometimes join forces to
149 simultaneously attack the same target prior to the initiation of a conflict with that target (i.e.
150 instantaneous or parallel coalitions, cf. Noë, 1986c; e.g. de Waal, 1982; Bissonnette, 2009). For
151 example, most chimpanzee male coalitions at Ngogo formed spontaneously or when the males
152 jointly retaliated after another male displayed in the vicinity (Watts, 2002). The term coalition covers
153 both of these interaction patterns, but excludes cases where an intervening animal breaks up an
154 agonistic interaction between two others without siding or “acting together” with either putative
155 combatant (referred to as “pacifying”, “neutral”, “policing”, “peaceful” or “impartial” interventions,
156 e.g. Bernstein, 1964; Boehm, 1994; Petit & Thierry, 1994; Roeder et al., 2002; Flack et al., 2006;
157 Rudolf von Rohr et al., 2012).

158 Three configurations of within-group coalitions formed by two partners against a single target have
159 been recognized (cf. Chapais, 1995; van Schaik et al., 2006; see Chapais 1995 for various examples in
160 primates):

- 161 (i) “all-down” (or “conservative”) when the coalition members outrank their target;
- 162 (ii) “bridging” when one partner ranks above and one partner ranks below the target;
- 163 (iii) “all-up” (or “revolutionary”) when both partners rank below their target.

164 Although some variation within- and across species has been reported (e.g. Harcourt, 1992; Boesch &
165 Boesch-Achermann, 2000; Young et al., 2014), all-down coalitions appear to be the most common
166 coalitionary pattern observed in animals when the beneficiary is not related to the supporter (e.g.
167 Harcourt & Stewart, 1989; Silk, 1993; Smith et al., 2010).

168 As we will see below, coalitions can serve different functions (van Schaik et al., 2006); they can be
169 observed among different sex and age classes (reviewed in Chapais, 1995); they can involve kin (e.g.

170 Riss & Goodall, 1977; Chagnon & Bugos, 1979b; Wahaj et al., 2004), non-kin (e.g. Vigilant et al.,
171 2001; Langergraber et al., 2007; Schuelke et al., 2010), and friends or acquaintances (Hruschka &
172 Henrich, 2006; Hruschka, 2010). As this brief review makes clear, coalitionary patterns are varied,
173 and understanding this diversity would be greatly enhanced by formal modeling that would allow us
174 to identify the general conditions under which coalition formation is expected to evolve, characterize
175 the degree of variability expected, and predict when coalitions should, and should not, occur. Below,
176 we summarize existing modeling approaches and highlight their main findings and predictions to
177 date.

178 **Modeling coalitions and alliances**

179 *General theoretical perspectives*

180 There exist four major mathematical theories that can provide insight into how coalitions and
181 alliances work (for more technical details see a recent review by Mesterton-Gibbons et al., 2011). Of
182 these, two have been most commonly applied to coalition formation. First, the *theory of endogenous*
183 *coalition formation* has been developed in the economics literature (Tullock, 1980; Skaperdas, 1996;
184 Skaperdas, 1998; Noh, 2002; Esteban & Sákovics, 2003; Garfinkel, 2004; Bloch et al., 2006; Sánchez-
185 Pagés, 2007; Konrad & Kovenock, 2009; Stamatopoulos et al., 2009; Tan & Wang, 2010). This theory
186 aims to predict coalitionary strategies that maximize individual fitness given a particular (ecological)
187 situation, the costs and benefits of different actions, and the information available to individuals.
188 Most existing models of coalition formation in animals belong to this general framework, which
189 overlaps with evolutionary game theory (Noë, 1990; 1992; 1994; Pandit & van Schaik, 2003; van
190 Schaik et al., 2004; 2006; Connor & Whitehead, 2005; Whitehead & Connor, 2005; Mesterton-
191 Gibbons & Sherratt, 2007; Broom et al., 2009; Okasha, 2009). We will discuss a number of these
192 models in more detail below.

193 Second, the *theory of cooperative games* models situations where players that have pooled their
194 resources attempt to come to an agreement on how to divide the spoils (von Newmann &
195 Morgenstern, 1947; Kahan & Rapoport, 1984; Myerson, 1991; Ray, 2007; Gilles, 2010). Coalitionary
196 theory using this perspective on cooperation predicts which coalitions can form and how the benefits
197 are distributed. Cooperative game theory proved to be useful in the study of human behavior, but
198 has rarely been applied to coalitions in non-human animals. This is at least partly because it remains
199 unclear how animals could negotiate without language and how any agreement could be enforced
200 (McNamara et al., 2006; Akcay & Roughgarden, 2007; Binmore, 2010). One notable exception is Noë
201 (1990), who used a veto game from cooperative game theory to explain patterns of coalition
202 formation among adult males in a group of wild baboons. In the veto game, there is a single “strong”
203 player who is able to claim (i.e., without negotiating) most of the spoils by playing other individuals
204 against each other. The power of a veto player may also be based on a unique skill, or possession of a
205 unique resource. A key player playing off two partners against each other is a situation that has been
206 described for both captive and wild chimpanzees (de Waal, 1982; Nishida, 1983; Muller & Mitani,
207 2005), and primate negotiation without language is discussed by de Waal (1996) and Melis et al.
208 (2009).

209 Third, the *theory of dynamic linking and network formation* focuses on dyadic or polyadic games
210 played by individuals in which the outcomes of previous interactions determine who interacts with
211 whom in the future (Skyrms & Pemantle, 2000; Pemantle & Skyrms, 2004a; 2004b; Hruschka &
212 Henrich, 2006; Santos et al., 2006; Pacheco et al., 2006; 2008; Gavrillets et al., 2008; Aktipis, 2011).
213 We discuss one application of this theory below.

214 Fourth, *coagulation-fragmentation theory* studies the dynamics of the population structure given
215 some simple rules concerning the mechanisms by which individuals join and leave groups (which in
216 our context can be thought of as representing coalitions). Its origins go back to a 1917 study of
217 polymers by Smoluchowski (Wattis, 2006), and have only recently found a way into the social
218 sciences (Eguíluz & Zimmermann, 2000; Bohorquez et al., 2009; but see: Cohen, 1972). This

219 promising approach will not be discussed further in this paper because it has not yet been applied to
220 coalitionary behavior in animals.

221 *Specific goals of theoretical models*

222 From a biological perspective, there are three major sets of questions that modelers aim to answer.
223 First, which strategies maximize individual fitness? Second, which coalitionary patterns are expected
224 to emerge, and how do they affect individual fitness and behavior? Third, how do the behavioral
225 rules used by individuals evolve and what are the individual and group level consequences of such
226 evolution? To illustrate how theoreticians address these questions, we discuss several recent models
227 in more detail and present their central assumptions in Table 1.

228 Fitness maximization

229 An overwhelming majority of coalitionary models focuses on determining which of a possible set of
230 coalitionary strategies maximizes individual fitness, given specific assumptions about the costs and
231 benefits to individuals, as well as the group composition and the information available to individuals.
232 Typically these models involve only three individuals. One of the oldest models is the one of
233 "minimally winning coalitions" of Riker (1962), i.e. rational players form coalitions in which the
234 pooled resources are as small as possible yet sufficient to win. In a more detailed analysis,
235 Stamatopoulos et al. (2009) investigated how differences in strength between three individuals
236 competing for a unit of divisible resource affect whether coalitions of two against one will emerge
237 and which individuals will form them. In their model, they assumed that: (a) the strength of a
238 coalition is given by the sum of the strengths of its participants, (b) the probability of winning a fight
239 (and thus obtaining the resource) is given by a logistic function of the difference in strengths, (c) a
240 winning coalition divides the reward in proportion to the strengths of the individuals in the coalition,
241 and (d) the costs of fighting are absent. Using additional assumptions about how the reward is
242 divided if no coalition is formed, Stamatopoulos et al. (2009) showed that if the strongest individual
243 is sufficiently strong relative to the weakest members, the latter should form an all-up coalition

244 against the former. If the strengths of the two strongest members are relatively close to that of the
245 weakest member, they should form an all-down coalition. In all other cases, the strongest and the
246 weakest players should form a bridging coalition against the medium-strength player. Consistent
247 with one of the model's prediction, Benenson et al. (2009) found that human subjects are
248 increasingly willing to form coalitions as their own level of perceived strength diminishes.

249 Broom et al. (2009) studied the effects of coalitionary support by kin on the stability of dominance
250 hierarchies in group-living animals. Their model considers a conflict between a high-ranking
251 individual and a challenger seeking to replace it in the hierarchy. The conflict is observed by a third
252 individual who can decide to help one of the two parties. Helpers derive only indirect fitness benefits
253 as a consequence of their relatedness to the main actors. Specifying the costs and benefits of
254 different actions, Broom et al.'s (2009) model predicts who should attack whom under which
255 circumstances. An interesting prediction is that increased variance in relatedness within a group, but
256 not the mean relatedness, makes formation of coalitions more plausible (i.e. if variance in
257 relatedness is low, regardless of the mean degree of relatedness among all individuals, coalitions will
258 not occur).

259 Using a similar approach, van Schaik and colleagues (Pandit & van Schaik, 2003; van Schaik et al.,
260 2004; 2006) aimed to predict the type of coalitions formed (i.e. all-up, bridging, or all-down; rank-
261 changing or leveling) in a group of males competing for fertilization opportunities. They considered
262 primate males living in groups of an arbitrary size, where individuals ranked in a linear hierarchy
263 compete over increases in ranks. van Schaik et al. (2004; 2006) assumed: (a) that the relationship
264 between the rank and fitness pay-off is exponential, (b) that coalitions are formed only against a
265 single target, (c) that coalition strength is given by a sum of the strengths of its participants, and (d)
266 that the stronger party always wins. Using an idealized cost parameter, van Schaik et al. (2004; 2006)
267 identified regions of parameter space where coalitions were both feasible (i.e., are stronger than the
268 target) and profitable. Building on these results, van Schaik et al. (2004; 2006) made a number of
269 testable predictions. For example, they predicted that all-up rank-changing coalitions should (a) arise

270 only in groups with a medium degree of despotism, (b) be a small coalition (two or three members),
271 (c) target the top individual, and (d) involve individuals ranking just below the target. Recent
272 empirical tests have provided support for some predictions of the Pandit/van Schaik model in
273 primate males (Jones, 2005; Bissonnette, 2009; Higham & Maestriperi, 2010; but see Kulik et al.,
274 2012), although important limitations of the approach have also been discussed (Bissonnette, 2009;
275 Berghänel et al., 2010; Young et al., 2014).

276 There is a general criticism of the optimization approach embodied in fitness maximization
277 models. Specifically, the applicability of this approach hinges on the assumption that the optimal
278 strategies identified in the mathematical models are (or closely approximate) the strategies used by
279 real individuals. How can animals know what the best strategies are? One common answer is that
280 natural selection is able to find the best strategy so that organisms have evolved to develop an
281 optimum “coalitional psychology”. Given the multiplicity and interdependence of possible
282 behaviors and the complexity of resulting evolutionary dynamics in a coalitional context, this
283 answer is not entirely satisfactory (McNamara & Houston, 2009). Also, it is possible that the
284 optimization problem has multiple alternative solutions, which means that the most relevant
285 solution is not always obvious.

286 From behavioral rules to coalitional patterns

287 An alternative approach is to predict group level coalitional patterns and their effects on individual
288 fitness and behavior, given the assumptions listed above, as well as some additional assumptions
289 about how individuals interact in dyadic and polyadic conflicts. For example, using the theory of
290 dynamic linking, Gavrilets et al. (2008) examine the theoretical plausibility of an argument about the
291 role of coalitions in the “egalitarian revolution” (Boehm, 1999), which is suggested to have resulted
292 in a transition from the hierarchical societies characteristic of chimpanzees to the egalitarian
293 societies seen among human hunter-gatherers. Gavrilets et al. (2008) found support for Boehm’s
294 arguments and further suggested that the transition required a change in cognitive abilities. Gavrilets

295 et al. (2008) assumed that decisions regarding whether to join a coalition were based on a simple
296 heuristic rule that utilized the relative “affinities” of a potential helper to the two individuals engaged
297 in conflict. These “affinities” reflected the history of past interactions and changed via a process akin
298 to reinforcement learning: that is, they increased following a mutually beneficial interaction and
299 decreased following an agonistic interaction. Affinities also continuously decayed to zero reflecting a
300 loss of memory by the helpers and actors (or alternatively, the discounting of distant events in the
301 past). Affinities thus represent a simple alternative to explicit fitness considerations. A particularly
302 attractive feature of Gavrilets *et al.*’s (2008) model and similar approaches (e.g. Pacheco et al., 2008)
303 is that they are scalable, i.e. they can easily be generalized to larger groups and multiple coalitions.
304 Of course this would require individuals to be able to memorize a larger number of affinities. One
305 serious limitation to this approach must also be emphasized, however: there is no guarantee that the
306 heuristic rules used in this and similar models are evolutionarily stable. Consequently, the
307 “coalitional psychology” postulated in these models is, potentially, biologically irrelevant. This is
308 clearly an area on which empirical research can shed more light by testing which decision rules are
309 used in coalitional conflicts.

310 Evolution of behavioral rules and its consequences

311 Analysis of evolutionarily stable strategies has been an extremely important tool in theoretical
312 studies of animal behavior (Maynard Smith, 1982). There are, however, only a few models that
313 explicitly study the emergence of evolutionarily stable behavioral rules in a coalitional context (thus
314 combining the two approaches outlined above). These models make specific assumptions with
315 respect to possible coalitional strategies, their costs and benefits, the information available to
316 individuals, and the behavioral rules followed by individuals. Mesterton-Gibbons and Sherratt
317 (2007), for example, consider competition among three individuals in a setup similar to that of
318 Stamatopoulos et al. (2009) and Broom et al. (2009). A crucial novel feature of their model, however,
319 is the assumption that individuals differ with respect to a genetically controlled trait (“alliance
320 threshold”) that determines whether an individual seeks coalitional aid (if his strength falls below

321 threshold) or goes it alone (if his strength exceeds threshold). Mesterton-Gibbons and Sherratt
322 (2007) also allow for incomplete information about the strengths of other individuals, for
323 dependence of fighting costs on the strengths of competitors, and for synergy/antergy between
324 individual strengths in determining pooled strength. They investigated how evolutionarily stable
325 alliance threshold values (which determine evolved “coalitionary psychology”) depend on various
326 parameters of their model. In particular, they predicted that 2-versus-1 coalitions are more likely to
327 occur when (a) the reliability of strength as a predictor of contest outcome is high, (b) there is high
328 variation in fighting strengths, and counterintuitively (c) when the effective strength of a coalition is
329 less than the sum of its individual strengths (see also Mesterton-Gibbons & Sherratt, 2009; Gavrilets,
330 2012). Using similar methods for identifying evolutionary stable behaviors in various coalitionary
331 contexts would greatly inform the theory (but will likely be quite challenging mathematically).