

Appendix 1: SESF variables for beekeeping SES are listed with their definitions and methods used to identify them.

Sources are listed if variable is found in published or unpublished literature. Note that both, SESF guiding literature and literature looking at bee systems explored to identify variables. In addition to literature, online sources such as government websites, rules and regulations had also supported variable identification process,

SESF variable for beekeeping industry (Focal SES)	Definition/Description	Tier	Method†				Sources ‡
			L	I	O	W	
Governance System (GS)	Bee governance system	1	√	√	√	√	9, 11
Government organization (GS1)	Government organizations managing and monitoring action situation for beekeeping industry system	2	√	√	√	√	2, 9, 11, 12
National level government organization (GS1a)	Federal government	3	√	√	√	√	2
State level government organizations (GS1b)	State government	3	√	√	√	√	2
Local Government (GS1c)	Local government	3		√		√	
Non-government org (GS2)	Presence of non- government organization managing and monitoring action situation for beekeeping industry system	2	√	√	√	√	2, 9, 11, 12
Industry organizations (GS2a)	Industry owned and operated organizations that collectively represent various beekeepers associations (e.g. BICWA)	3		√	√	√	
Beekeepers associations (GS2ai)	Presence of various beekeepers associations such as commercial, semi-commercial and hobby beekeepers associations	4		√		√	
Queen breeders (GS2aii)	Queen bee breeders group that rears and provides queen bees to the state due to closed borders	4		√	√	√	
Industry leaders (GS2aiii)	Leading WA beekeepers who are positioned at industry organizations, involved in lobbying activities, brings investment for the development of the industry, provide	4				√	

	knowledge about resources and beekeeping techniques to new beekeepers							
Research organizations (GS2b)	Organizations actively engaged in research related to various aspects of the beekeeping industry	3	√	√	√	√		17
University research (GS2bi)	Student and researchers from universities involved in the research beneficial to the beekeeping industry	4		√		√		
Industry funded research (GS2bii)	Research funded by industry owned and operated organizations (targets industry specific issues, beekeeper researchers)	4		√		√		
Cooperative Research centres (CRCs)	Collaborative research involvement from government, non-government organizations (e.g. CRC for honeybee products)	4		√	√	√		
Network Structure (GS3)	Social or political connections among government / no-government organizations, beekeepers and other industry stakeholders.	2	√	√	√	√		2, 9, 11, 12
Social network (GS3a)	Social connections between beekeepers and government or private land owners/managers	3	√	√	√	√		2
Informal beekeeper groups (GS3ai)	Information flows among groups of beekeepers (e.g. information regarding resource availability and access)	4		√		√		
Market network (GS3b)	Presence or absences of multilevel of market structure and associated interactions	3		√				
Local farmers' market (GS3bi)	Regular or occasional local markets and fresh food produce outlets	4		√		√		
Supermarkets (GS3bii)	Supermarket networks	4		√		√		
Export market (GS3biii)	Export market and associated interactions	4		√	√	√		
Property rights systems (GS4)	Presence of property rights system governing access to forage resources (e.g. private property, common property, restricted access)	2	√	√	√	√		2, 9, 11, 12
Operational choice rules (GS5)	Presence of formal written rules for access and/or harvesting from the forage resources	2	√	√	√	√		2, 9, 11, 12
Collective choice rules (GS6)	Rules defined by involved stakeholders following their understanding of local social, ecological and political conditions	2	√		√	√		2, 9, 11, 12
Constitutional choice rules (GS7)	Law, act or mandates defined by regional or national level government	2	√	√	√	√		2, 9, 11, 12
Act relating to beekeeping activity (GS7a)	Biosecurity and Agriculture Management Act 2007	3		√	√	√		19

Act relating to biosecurity (GS7b)	Biosecurity and Agriculture Management Regulation 2013	3	√	√	√	19
Acts relating to access and use of resources (GS7c)	Conservation and land management Act 1984, , Biodiversity Conservation Act 2016 and Biodiversity Conservation Regulations 2018	3	√	√	√	22
Conditions for using resources available on Government owned land (GS7ci)	General Conditions for using Apiary Authorities on Crown land in Western Australia	4	√	√	√	24
Forest management plans (GS7cii)	Planning for management of forest used for apiary authority	4	√	√	√	20
Local government Acts or Bylaws (GS7ciii)	Verge treatment/spraying , regulations relating to keeping bees in neighbourhood	4	√		√	
Conditions for using resources managed by managers other than government (GS7civ)	Recreation, mining, timber and logging, pastoral leases	4	√	√	√	23
Requirements relating to food handling, processing and labelling (GS7d)	Regulation for extraction, processing, packing and labelling of honey	3	√		√	21
Monitoring and sanctioning rules (GS8)	Presence of authority to for resource monitoring and access sanctioning	2	√	√	√	2, 9, 11, 12
Sanctioning rules (GS8a)	Process of sanctioning authority to access the resources	3	√	√	√	2
Apiary permits (GS8ai)	Authority to place beehives on forage locations	4	√	√	√	16, 26
Clearing permits (GS8aai)	Authority to clear vegetation to gain physical access and place beehives on forage locations	4	√	√	√	24
Monitoring rules (GS8b)	Process of monitoring resource availability and usage	3	√	√	√	2
Apiary site monitoring (GS8bi)	Monitoring resource use on apiary authority	4	√		√	
Monitoring beehives (GS8bii)	Monitoring requirement and availability of required resources	4	√		√	
Actors (A)	Beekeepers	1	√	√	√	7, 9, 11

Number of actors (A1)	Number of beekeepers	2	√	√	√	√	9, 12
Socio-economic attributes (A2)	Socio-economic characteristics of beekeepers	2	√	√	√	√	2, 9, 11, 12
Demographic attributes (A2a)	Age of beekeepers	3	√	√	√	√	2, 13
Intergenerational beekeeper (A2ai)	Beekeeping generation	4		√	√	√	
Economic attributes (A2b)	Economic characteristic of beekeeper	3	√	√	√	√	2
Large-scale operators (A2bi)	Beekeepers more than 500 hives	4		√	√	√	
Small-scale operators (A2bii)	Beekeeper less than 500 hives	4		√	√	√	
Equipment manufacturer/supplier (A2biii)	Manufacturer / supplier of beekeeping equipment (May or may not be keeping bees)	4		√		√	
Producer, packers and queen bee breeders (A2biv)	Beekeepers involved in honey packing or queen breeding	4		√	√	√	
Social attributes (A2c)	Presence of mutual support, cooperation and leadership quality	3	√	√	√	√	2
History of past experience (A3)	Duration of involvement in beekeeping	2	√	√	√	√	2, 9, 11, 12
Location (A4)	Residential location of beekeepers	2	√	√	√	√	2, 9, 11, 12
Leadership/ Entrepreneurship (A5)	Presence of educated and well-connected leader who is respected by their peers	2	√	√	√	√	2, 9, 11, 12
Volunteer leaders (A5a)	Active beekeeper to lead collective action	3		√	√	√	
Training for beekeeping business (A5b)	Beekeeper involved in providing formal/informal training for new beekeepers	3		√		√	
Norms and social capital (A6)	Closeness of community	2	√	√	√	√	2, 9, 11, 12
Social interaction (A6a)	Interactions and knowledge exchange among beekeepers	3		√		√	
Trust among actors (A6b)	Level of trust among beekeepers	3		√	√	√	
Relationship with other actors (A6c)	Relationship of beekeepers with actors other than the focal SES (e.g. farmers, local residents, consumers)	3		√		√	

Knowledge of SES models (A7)	Presence/ degree of Local ecological knowledge (LEK)	2	√	√	√	√	2, 9, 11, 12
Local knowledge on SES (A7a)	Spatial- temporal knowledge of floral source and understanding of effects of beekeeping activities on local environment	3	√	√	√	√	2, 12
Knowledge of concepts such as conservation, human-nature relationships (A7b)	Presence / degree of understanding of concepts like conservation, ecosystem services and human-nature relationship	3	√	√	√	√	2, 12
Knowledge of the biological shocks on SES (A7c)	Level of knowledge of the potential and real disturbance patterns and its possible effects	3	√	√	√	√	2, 12
Importance of resource (dependence) (A8)	Livelihood dependence on bee resources	2	√	√	√	√	2, 9, 11, 12
Full-time operators (A8a)	Completely depend on beekeeping for livelihood	3		√	√	√	
Part-time operators (A8b)	Has a source of income other than beekeeping	3		√	√	√	
Technologies available (A9)	Technologies used to identify, extract, harvest and manage the resource (A9)	2	√	√	√	√	2, 9, 11, 12
Resource system (RS)	Bee resources - Resources that produce melliferous flora	1	√	√	√	√	7, 9, 11
Sector (RS1)	Bee resources available on various sector (e.g. forest)	2	√	√	√	√	2, 9, 11, 12
Forest flora (RS1a)	Bee resources available from trees and other understorey plants in forest	3	√	√	√	√	7
Agriculture flora (RS1b)	Bee resources available from agriculture crops	3	√	√	√	√	7
Other plantation (RS1c)	Bee resources available from plantation	3	√	√	√	√	7
Revegetation (RS1ci)	Bee resources available from revegetation	4	√	√	√	√	7
Verge plantation (RS1cii)	Bee resources available from plantation on new or existing verge	4	√	√		√	6
Clarity of system boundary (RS2)	Clarity of the system's geographical, social and legal boundaries	2	√	√	√	√	2, 9, 11, 12
Geographic boundaries (RS2a)	Geographic boundary of bee resources	3	√				2
Anthropogenic boundaries (RS2b)	Fences or other human constructed boundaries	3	√	√	√	√	2

Individual's resource access boundary (RS2c)	User-defined boundary for the bee resources	3	√	√	√	√	2, 18
Size of the resource system (RS3)	Spatial extent and its area of bee resources	2	√	√	√	√	2, 9, 11, 12
Area covered by geographic extent of bee resources (RS3a)	Total area for bee resources	3	√	√	√	√	18
Size of different types of ecosystems within the extent of bee resources (RS3b)	Total area for each sector of bee resources	3	√		√		18
Fragmentation dynamics (RS3c)	Frequency of fragmentation over time	3	√		√		18
Human constructed facilities (RS4)	Anthropogenic structures supporting resource access and management	2	√	√	√	√	2, 9, 11, 12
Infrastructure e.g. road, highways (RS4a)	Availability of infrastructure for movement (e.g. roads, access ways) or as impediments (e.g. dams, fence)	3	√	√	√	√	2, 18
Water resources (RS4b)	Proximity to the nearest water resources	3		√		√	
Other facilities (RS4c)	Recreation facilities	3		√		√	
Productivity of the system (RS5)	Estimation about potential productivity of the area	2	√	√	√	√	2, 9, 11, 12
Resource dynamics (RS5a)	Regularity of flowering events	3	√	√	√	√	18
Natural resource dynamics (RS5ai)	Natural availability or unavailability of flowering event e.g. annual, biannual flowering frequency	4		√	√	√	
Resource dynamics in response to human disturbances (RS5aii)	Availability or unavailability of flowering due to man-made changes e.g. flowering event after species recovery from prescribed fire	4		√	√	√	
Resource diversity (RS5b)	Diversity of bee flora species	3	√	√	√	√	1
Equilibrium properties of the system (RS6)	Positive or negative influences on the equilibrium of the bee resources (e.g. seasonality, rainfall trends)	2	√	√	√	√	2, 9, 11, 12
Frequency of disturbances (RS6a)	Frequency of external impacts and system response e.g. frequency of draught/fire events and species recovery	3	√	√	√	√	18
Extent of disturbances (RS6b)	Extent of external impacts and system response e.g. extent of draught/fire events and species recovery	3	√	√	√	√	18

Intensity of disturbances (RS6c)	Intensity of external impacts and system response e.g. Intensity of draught/fire events and species recovery	3	√	√	√	√	18
Predictability of system dynamics (RS7)	Degree to which beekeepers are able to forecast/identify patterns in productivity of bee resources	2	√	√	√	√	2, 9, 11, 12
Probability of driving forces leading to system dynamics (RS7a)	Probability of driving forces e.g. uncertain nature of rainfall or natural fire events	3	√	√	√	√	18
Variability of driving forces leading to system dynamics (RS7b)	Variability of driving force e.g. variation in nectar production	3	√	√	√	√	18
Storage characteristics (RS8)	Information storage regarding effects of disturbances on bee resources	2	√	√	√	√	2, 9, 11, 12
Location and association (RS9)	Spatial configuration and extent of bee flora where system can be accessed by the beekeepers	2	√	√	√	√	2, 9, 11, 12, 18
Ecosystem history (RS10)	History of ecosystem dynamics	2	√	√	√	√	18
History of natural disasters (RS10a)	History of draught or bush fire events	3	√	√	√	√	18
History of anthropogenic use and disturbances (RS10b)	History of prescribe burn events	3	√	√	√	√	18
Resource unit (RU)	Beehives managed by beekeepers	1	√	√	√	√	5, 9, 11
Mobility of Resource units (RU1)	Beehive migration patterns	2	√	√	√	√	2, 9, 11, 12
Stationary Resource units (RU1a)	Stationary (non-migratory) beehives	3	√	√		√	18
Mobile Resource units (RU1b)	Migration patterns of beehives	3	√	√	√	√	9, 11, 18
Growth or replacement rate (RU2)	Absolute or relative descriptions of changes in quantities (x) of beehives over time (t)	2	√	√	√	√	2, 9, 11, 12
Interactions among resource units (RU3)	Interactions among beehives managed by same or different beekeeper	2	√	√	√	√	2, 9, 11, 12
Intraspecific interaction (RU3a)	Resource competition within honeybee species e.g. Hive robbing	3	√	√	√	√	18

Proximity of resource units (RU3ai)	Inter/intra colony distance among beehives	4	√	√	√	10, 24
Interactions damaging resource unit conditions (RU3aai)	Potential for disease transmission	4	√	√	√	10
Interspecific resource competition (RU3b)	Resource competition among nectarivorous species e.g. for nesting or forage resources	3	√	√	√	18
Value of resource unit (RU4)	Value of a beehive	2	√	√	√	2, 9, 11, 12
Market value (RU4a)	Cost associated with a beehive (e.g. levy, insurance etc.)	3	√	√	√	2
Environmental value (RU4b)	Non-monetary value of a beehive (e.g. importance for pollination)	3	√	√	√	2
Strategic value (RU4c)	Social/cultural value of a beehive (e.g. importance as a hobby)	3	√	√	√	2
Number of units (RU5)	Number of managed hives	2	√	√	√	2, 9, 11, 12
Number of units leading to economic benefit (RU5a)	Hives managed for economic benefits	3		√	√	
Load size (RU5ai)	Number of hives managed for honey production	4		√	√	
Number of units leading to economic and environmental benefits (RU5b)	Hives managed for pollination services	3		√	√	
Distinctive characteristics (RU6)	Colouring / numbering of hives aiming identifying individual loads	2	√	√	√	2, 9, 11, 12
Distinctive markings (RU6a)	Marking beehives with brand code	3	√	√	√	
Spatial and Temporal distribution (RU7)	Beehive migration patterns	2	√	√	√	2, 9, 11, 12
Spatial patchiness (RU7a)	Hive migration on fragmented landscape	3	√	√	√	18
Temporal patchiness (RU7b)	Hive migration following phenology and patchy flowering	3	√	√	√	18
Interactions (I)	Key activities and processes in beekeeping	1	√	√	√	9, 11
Harvesting (II)	Quantity of honey harvested	2	√	√	√	2, 9, 11, 12

Harvesting levels of different resource users (I1a)	Quantity of honey harvested by different beekeepers	3	√	√	√	√	2
Harvesting levels from different locations (I1b)	Quantity of honey harvested from different forage locations	3	√	√	√	√	14
Information sharing (I2)	Methods of information sharing among beekeepers	2	√	√	√	√	2, 9, 11, 12
Information sharing within formal resource user organization (I2a)	Information sharing within formal beekeeper groups	3		√	√	√	
Information sharing within informal resource user groups (I2b)	Information sharing among informal beekeeper groups	3		√	√	√	
Information sharing between resource user organization and government organizations (I2c)	Information sharing between government and industry organization	3		√	√	√	
Deliberation process (I3)	Presence of organizational structure for beekeepers' participation in decision making process	2	√	√	√	√	2, 9, 11, 12
Conflicts (I4)	Presence of existing conflicts among beekeepers and between beekeepers and other actors	2	√	√	√	√	2, 9, 11, 12
Conflicts among resource users (I4a)	Presence of conflicts among beekeepers	3		√		√	
Conflicts between resource users and other actors (I4b)	Presence of existing conflicts between beekeepers and other actors including government organizations	3		√	√	√	
Investment activities (I5)	Investment for improving and managing bee resources	2	√	√	√	√	2, 9, 11, 12
Investment in resource improvement and management (I5a)	Investment in resource improvement schemes	3		√	√	√	
Investment in industry relevant research and development activities (I5b)	Investment in research and development activities	3		√	√	√	
Lobbying activities (I6)	Presence of influential beekeepers	2	√	√	√	√	2, 9, 11, 12
Self-organizing activities (I7)	Internal rules made by beekeepers for resource extraction and management	2	√	√	√	√	2, 9, 11, 12

Networking activities (I8)	Networking and partnership activities among and outside beekeeper groups	2	√	√	√	√	2, 9, 11, 12
Monitoring activities (I9)	Monitoring activities on the use and management of resources	2	√	√	√	√	2, 9, 11, 12
Resource use monitoring activities (I9a)	Activities for monitoring bee resources	3		√		√	
Resource unit monitoring activities (I9b)	Beehive monitoring activities	3		√		√	
Evaluation Activities (I10)	Process of evaluation of resource condition and management initiatives	2	√	√	√	√	2, 9, 11, 12
Outcomes (O)	Beekeeping Outcomes (from key activities and processes)	1	√	√	√	√	9, 11
Socio-economic performance measure (O1)	Efficiency, equity and sustainability in apiary production	2	√	√	√	√	2, 9, 11, 12
Ecological performance (O2)	Biodiversity, resilience and sustainability of the bee resources	2	√	√	√	√	2, 9, 11, 12
Externalities to other SES (O3)	Non desired effects that occur as a result of processes	2	√	√	√	√	2, 9, 11, 12
Positive externalities (O3a)	Non desired positive effects that occur as a result of processes	3	√	√	√	√	2
Plant pollination (O3ai)	Unpaid plant pollination as a result of beehive migration process	4		√	√	√	
Packaged industries (O3aai) e.g. ecotourism,	Innovative industry model inspired from social-ecological benefits	4		√	√	√	
Negative externalities (O3b)	Non desired negative effects that occur as a result of processes	3	√	√	√	√	2
Resource competition with other species (O3bi)	Resource competition with other nectarivorous animals	4	√	√	√	√	4, 8
Disease transmission (O3bii)	Potential for disease transmission	4	√	√	√	√	3
Related ecosystems (ECO)	Other related ecosystems	1	√	√	√	√	9, 11
Climate pattern (ECO1)	Climate change or other biophysical change in the system	2	√	√	√	√	2, 9, 11, 12
Pollution pattern (ECO2)	Presence of toxic chemicals or materials	2	√	√	√	√	2, 9, 11, 12

Flows in and out of SES (ECO3)	Flows into and out of the focal SES	2	√	√	√	√	2, 9, 11, 12
Social, economic, and political settings (S)	Social, economic and political settings in which focal SES is located in	1	√	√	√	√	9, 11
Economic development (S1)	Economic growth of the area	2	√	√	√	√	2, 9, 11, 12
Demographic trend (S2)	Population growth and trends	2	√	√	√	√	2, 9, 11, 12
Political Stability (S3)	Regulatory framework of the region	2	√	√	√	√	2, 9, 11, 12
Other governance system (S4)	Traditional tenure or other government policies	2	√	√	√	√	2, 9, 11, 12
Markets (S5)	Environmental awareness and market demand	2	√	√	√	√	2, 9, 11, 12
Media organizations (S6)	Number, diversity and freedom of private and public media	2	√	√	√	√	2, 9, 11, 12
Technology (S7)	Presence of relevant technology	2	√	√	√	√	9, 11, 12

† Method column represent different methods used for stakeholder involvement: L – Literature research, I – Semi-structured interviews, O – Open ended discussion, W – Workshop with retired beekeepers.

‡ Numbers corresponds to the sources listed below.

Sources

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